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ECONOMIC GEOLOGY

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VOL. XLIII MARCH–APRIL, 1948 No. 2

ON HYDROTHERMAL DIFFERENTIATION.

HENRICH NEUMANN.

INTRODUCTION.

DURING recent years various authors have discussed the circumstances under which exudation of a hydrothermal solution marks the final stages in the consolidation of a magma.[1] In general, two main possibilities can be envisaged:

(a) The hydrothermal solution may constitute a residual fluid remaining after the crystallization of the parental igneous rock.
(b) The hydrothermal solution may separate as an independent phase coexisting with the magma-phase on the one hand and with the solid phase (the rock) on the other.

The first alternative would appear to be the more probable from a purely geological point of view, since it provides a natural explanation of the fact that hydrothermal veins are younger than their cogenetic pegmatite dikes. It implies, however, complete miscibility between silicate-melt and hydrous solution, a conclusion which is not confirmed by the few experimental data at present available.[2] In the opinion of the writer, therefore, serious consideration must be given to the second alternative, *i.e.*, to the possible co-existence of the fluid (hydrothermal solution), molten (magma), and solid (rock) phases during the final stages of magmatic crystallization.

The time relationship which exists between hydrothermal veins and cogenetic pegmatite dikes may be explained further by an analysis of the physical conditions under which exudation of the hydrothermal solution takes place.[3]

On the assumption that the three phases exist in equilibrium, the history of the magma can be outlined from the inception of crystallization until consolidation is complete. One must postulate that the original magma, at the beginning of crystallization, contained a certain quantity of water in excess of that

[1] A summary and discussion of the different views is presented by L. C. Graton in ECON. GEOL., XXXV, S. 2, pp. 197–358, 1940. See also the reply of Earl Ingerson and G. W. Morey, ECON. GEOL., XXXV, No. 6, pp. 772–785, 1940.

[2] R. W. Goranson: The solubility of water in granite magmas, Am. Jour. Sci., 5th ser., XXII, pp. 481–502, 1931, and others.

[3] This paper, p. 78.

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finally taken up by the igneous rock. For granitic or granodioritic magmas, which are the most common parental magmas of hydrothermal deposits, this original amount would probably be about 1 percent H_2O. As crystallization proceeded the remaining molten magma would become relatively enriched in water until it reached a saturation point. Thereafter further crystallization would result in the exudation of water as a separate phase, and this process might be expected to continue until crystallization was complete although at the same time the water content of the magma itself would have remained practically constant.[4] How great the water content of the saturated magma would be depends, apart from the chemical composition of the melt itself, mainly on the existing outer pressure. The investigations of R. W. Goranson [5] indicate that the saturation point of a granitic magma will be about 10 percent H_2O under favorable outer pressure conditions.

HYDROTHERMAL DIFFERENTIATION.

From investigations of areas where hydrothermal veins of different types occur, several authors have arrived at the conclusion that hydrothermal solutions which have left the more or less solidified magma must have been of different chemical composition at different times. However, as far as the present writer knows, no attempt has yet been made to formulate the laws governing such a hydrothermal differentiation.

Provided that the outline given above of the last stage of the freezing of the magma is accepted, a further analysis of the conditions will, however, reveal, first, that a differentiation must certainly take place, and second, why some compounds are concentrated in the first solutions exuded, while other compounds are concentrated in the later solutions.

During crystallization three phases will always be present in the magma chamber from the moment that the saturation point with water is attained:

(a) Solid phase, the rock.
(b) Molten phase, the magma.
(c) Fluid phase, the hydrothermal solution.

Every compound in the magma chamber will, in accordance with the distribution law, distribute itself between the three phases in proportion to the solubilities in each phase. To simplify this survey of hydrothermal differentiation the writer has considered the actual compounds to be insoluble in the solid phase and, therefore, distributed between the molten and fluid phases only. For most of the typical hydrothermal compounds this will apply, but the writer is well aware that such will not be the case with other compounds. It does not, however, affect the general principle offered for consideration.

[4] It is supposed above that the walls of the magma reservoir are impermeable to vapors. Under natural conditions, however, one must realize that some water can escape from the crystallizing magma, as the outer pressure may become less than the vapor pressure, owing to the porosity of the surrounding rocks, making these permeable to vapor, but impermeable to magma. Vapors, moreover, may escape from the magma chamber from the very beginning of crystallization to such an extent that the magma never becomes saturated with water at all. Ingerson and Morey (op. cit.) seem to think that this is the normal process, but even so hydrothermal differentiation would, nevertheless, take place in the manner outlined in this paper.

[5] R. W. Goranson, op. cit.

The main task is thus to study the enrichment of a certain compound in the fluid phase considered as a function of: (1) the distribution-coefficient—$\frac{\text{solubility in fluid phase}}{\text{solubility in molten phase}}$—of the compound discussed, and (2) the quantity of molten phase which is converted into solid phase + fluid phase after the moment when the molten phase becomes saturated with water.

Two different cases must be considered:

(a) The fluid phase continuously disappears from the magma chamber immediately on its development, and

(b) The fluid phase remains in the magma chamber in equilibrium with the other phases until the magma is completely frozen.

The actual course in nature would very often lie between these two extremes, as it seems probable that either the hydrothermal solution will be removed by degrees from the magma chamber, or the rest of the magma will at some time be removed from the solid phase and the hydrothermal solution.[6]

If:

x = the fraction of water-saturated magma changed into solid phase + fluid phase,

y = the concentration of the actual compound in the fluid-phase,

Q = the original quantity of water-saturated magma,

t = the fraction of water dissolved in the water-saturated magma = $\frac{\text{fluid phase}}{\text{fluid phase + solid phase}}$;

k = the distribution coefficient = $\frac{\text{solubility in fluid phase}}{\text{solubility in molten phase}}$,

a = concentration of the actual compound in the magma at the moment the magma is saturated with water,

it is found, assuming that the fluid phase continuously disappears from the magma chamber immediately on its development:

$$(1) \qquad Qt\Delta x(y+\Delta y)+\frac{Q}{k}(1-x-\Delta x)(y+\Delta y)=\frac{Q}{k}(1-x)y;$$

letting x approach 0 one finds the process ruled by the differential equation:

$$(2) \qquad \frac{1}{1-kt}\frac{dy}{dx}=\frac{y}{1-x}.$$

Integrating this equation, and remembering that the quantity of the actual compound $= a$, for $x = 0$, one finds:

$$(3) \qquad y=ka(1-x)^{kt-1}.$$

Assuming that the fluid phase remains in the magma chamber in equilib-

[6] See "Physical conditions" below.

[7] For this investigation the only interest is in what happens to the magma after it has reached its "second boiling point." By "the quantity of solid phase" is therefore meant "the quantity of solid phase which has appeared after the magma is saturated with water."

rium with the magma until this is completely solidified, it follows:

$$(4)\quad Qtxy + \frac{Q}{k}y - \frac{Q}{k}xy = Qt(x+\Delta x)(y+\Delta y) + \frac{Q}{k}(1-x-\Delta x)(y+\Delta y);$$

from this,

$$(5)\quad \frac{dy}{dx} = \frac{(1-kt)y}{1+(kt-1)x},$$

which equation, as above, gives:

$$(6)\quad y = \frac{ka}{1+(kt-1)x}.$$

From the expressions (3) and (6) it is apparent:

(a) y increases with increasing x for $kt-1<0$, thus for $\frac{1}{k}>t$,

(b) y is constant (independent of x) for $kt-1=0$, thus for $\frac{1}{k}=t$,

(c) y decreases with increasing x for $kt-1>0$, thus for $\frac{1}{k}<t$,

or in other words: If the fluid phase is in equilibrium with the freezing magma during the whole process of freezing, or if it exudes from the magma chamber immediately on its appearance, then in both cases the following hold:

(a) *A compound will be enriched in the youngest hydrothermal solutions if for the actual compound the proportion* $\frac{\text{solubility in molten phase}}{\text{solubility in fluid phase}}$ *is greater than the solubility of water in the magma.* The enrichment in the youngest solutions will be the more distinct the greater the value of this proportion.

(b) *A compound will exist in the same quantity in the oldest and the youngest hydrothermal solutions if for the actual compound the proportion* $\frac{\text{solubility in molten phase}}{\text{solubility in fluid phase}}$ *is equal to the solubility of water in the magma.*

(c) *A compound will be enriched in the oldest hydrothermal solutions if for the actual compound the proportion* $\frac{\text{solubility in molten phase}}{\text{solubility in fluid phase}}$ *is smaller than the solubility of water in the magma.* The enrichment in the oldest hydrothermal solutions will be the more distinct the smaller the value of this proportion.

The curves shown in Fig. 1 demonstrate the variation of concentration in the fluid phase of compounds with different solubilities as the magma freezes.

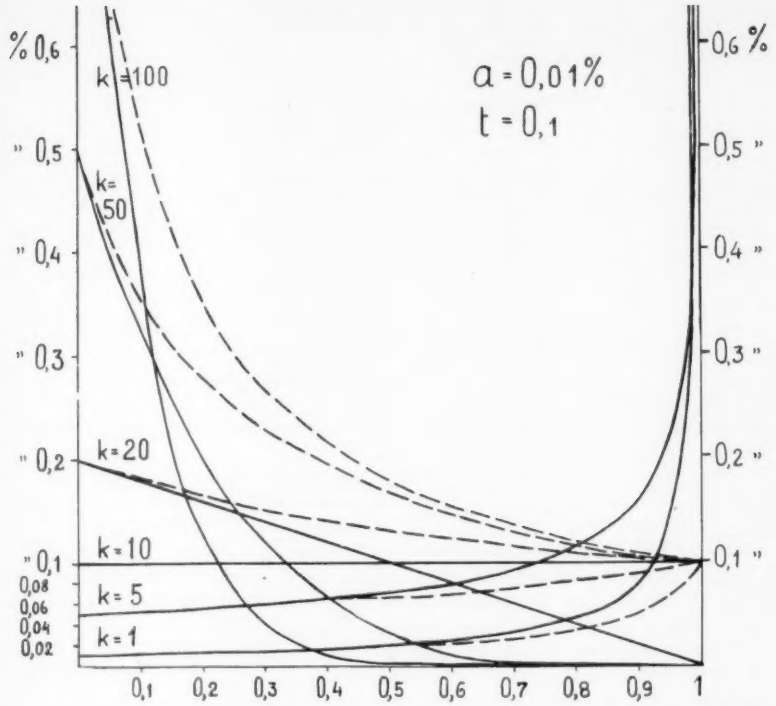

FIG. 1. Curves showing variation, as the magma solidifies, of concentration in the hydrothermal solutions of compounds with different solubilities. Concentration plotted along ordinate. Fraction of crystallized water-saturated magma along abscissae. k = distribution coefficient = $\frac{\text{solubility in solution}}{\text{solubility in magma}}$. a = quantity of actual compounds in the magma at the moment the magma is saturated with water. t = the fraction of water dissolved in water-saturated magma. Solid lines for hydrothermal solutions leaving the magma immediately on their appearance. Broken lines for hydrothermal solutions remaining in magma chamber, in equilibrium with magma and rock, until magma is completely solidified.

For the construction of the curves it is assumed that the magma becomes saturated with water when the concentration is 10 percent ($t = 0.1$), and further that the concentration of the actual compound in the magma is 0.01 percent at the moment the magma is saturated with water.

As is demonstrated above, from the supposition that a magma is immiscible with water at all temperatures and pressures it follows logically that the chemical composition of the fluid phase will change as the crystallization of the magma carries on. For this phenomenon of a magma giving off hydrothermal

solutions of different chemical compositions at different times the author proposes the term *endomagmatic hydrothermal differentiation.*

It is commonly considered by ore geologists that hydrothermal solutions, having left their magmatic source during their progress along fissures in the surrounding rocks, change their chemical composition, partly owing to the precipitation of the least soluble minerals with cooling and partly because of reactions between the solutions and the wall rocks (*cf.*, the phenomenon "telescoping"). For this differentiation, which has quite a different origin from that of the endomagmatic differentiation, as it takes place after the hydrothermal solutions have left their magmatic source, the author proposes the term *exomagmatic hydrothermal differentiation.*

PHYSICAL CONDITIONS.

Whether or not the fluid phase, which appears when the magma is saturated with water, is a gas or a liquid is disputed. The solubility of different compounds in the water phase is of prime importance for the endomagmatic hydrothermal differentiation, and obviously it is of equal importance, when discussing this solubility, to know in which of these two states the fluid phase exists.

There is, however, a third possibility which the writer regards as highly probable. In the last stage of crystallization the bulk of the original magma has solidified while a fraction remains as a water-rich residual magma. The contents of the magma chamber regarded as a unit will be a crystal mesh of solid minerals with the residual magma filling the interstices between the crystals. When the fluid phase separates there will, according to the customary view, appear greater or smaller water-concretions which rise through the crystal mesh as drops or bubbles. More probably, however, the newly formed fluid phase will approach and become attached to the phase borders between the solid mineral grains and the molten rest-magma. Thus the fluid phase after its appearance will be found, not as bubbles or drops in the crystal mesh, but as a thin film bound by adsorption around the mineral grains.

This adsorbed water will differ in its physical and chemical properties from water in either liquid or gas form, and with respect to the solubility properties of the water-phase one must consequently be careful in drawing conclusions based on our knowledge of the solubility properties of liquid or gaseous water at high pressures and temperatures.

As mentioned above (p. 77) this conception of the physical conditions in the magma chamber after the magma is saturated with water will also explain why the hydrothermal veins are younger than their cogenetic pegmatite dikes. One must suppose that the adsorbed water will be relatively immobile, as it is closely bound to the mineral grains, while on the other hand the water-rich silicate rest-melt will move fairly easily between the solid particles. Under the influence of pressure, therefore, the residual magma will be squeezed out at first, while the hydrothermal solution will leave the magma chamber later.

With the cooling of the magma chamber and its surroundings tension fissures will probably appear in the already frozen igneous rock and in the country rocks. These fissures will represent zones of lower pressure, and to ob-

tain stable pressure conditions mobile compounds in the magma chamber will be sucked into these zones. First, the residual melt will be sucked into the older low-pressure zones, and will solidify there as pegmatite dikes; later, the adsorbed water will be sucked into the younger low-pressure zones in the form of hydrothermal solutions, and will lead to the formation of hydrothermal veins.

The writer also offers for consideration the view that the bulk of the fluid phase will stay in the magma chamber and deposit *in situ* the compounds dissolved in it, as a fine, invisible dust on the surface of the rock-building minerals, and thus, as a rule, a smaller part only of the fluid phase will find its way into fissures as hydrothermal solutions, giving rise to mineral deposits.

The external geological conditions will in each case be the deciding factor for the formation of low-pressure zones, and will therefore also determine to what extent pegmatite dikes and hydrothermal veins appear in connection with the intrusion of molten magmas.

DEPARTMENT OF GEOLOGY,
UNIVERSITY OF LEEDS,
Dec. 24, 1947.

ROLE OF THE IDAHO BATHOLITH DURING THE LARAMIDE OROGENY.[1]

ALFRED L. ANDERSON.

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ABSTRACT.

As the Idaho batholith was emplaced just before the beginning of the Laramide orogeny, it formed a part of the hinterland on the west side of the Rocky Mountain geosyncline. Acting as a strong, rigid mass, it transmitted the orogenic forces into the thick succession of relatively weak sediments in the bordering trough, where the strata were forced into long regular folds of the Appalachian type, and broken by great low-angle thrusts.

Structural studies in scattered mining districts, within as well as outside the borders of the batholith, show that, in transmitting the forces, the batholith was not only locally deformed but also controlled deformation of the bordering formations. In many places the batholith was broken by minor thrusts of west-northwest trend and southwest (exceptionally northeast) dip. The granitic mass was also broken by many extensive transverse strike-slip faults trending northeast, apparently in response to horizontal shearing. The batholith influenced deformation of the thick Belt series for scores of miles to the north, where, during late stages of crustal shortening, transverse zones of faulting of general east-southeast trend were formed.

These transverse zones of structural weakness both within and outside the batholith facilitated and thus localized igneous intrusion and mineralization at the close of the orogeny. They also influenced deformation, igneous activity, and mineralization during a mid-Tertiary disturbance.

[1] Presented at the Ottawa meeting of the Geological Society of America, December, 1947. This presentation is the outgrowth of twenty years' study of the ore deposits in or near the Idaho batholith largely under the direction of the Idaho Bureau of Mines and Geology.

INTRODUCTION.

STRUCTURAL studies in scattered mining districts within as well as outside the borders of the Idaho batholith have disclosed that the batholith had a significant part in the Laramide orogeny. Emplaced in late Jurassic or Cretaceous time in rocks more or less extensively disturbed by the Nevadian orogeny,[2] it formed at the beginning of the Laramide orogeny a part of the hinterland on the west side of the Rocky Mountain geosyncline, where, because of its strength and rigidity, it transmitted the orogenic forces into the thick succession of relatively weak sediments in the bordering trough producing long regular folds of the Appalachian type and the great, much acclaimed, low-angle thrusts. Except for incidental mention by the writer in reports on several mining districts, little, if anything, has been written as to what happened to the batholith during the Laramide disturbance. Therefore, it is not generally known that the transmission of forces caused local deformation within the batholith and further had a profound effect on the deformation of the thick Belt series for scores of miles to the north.

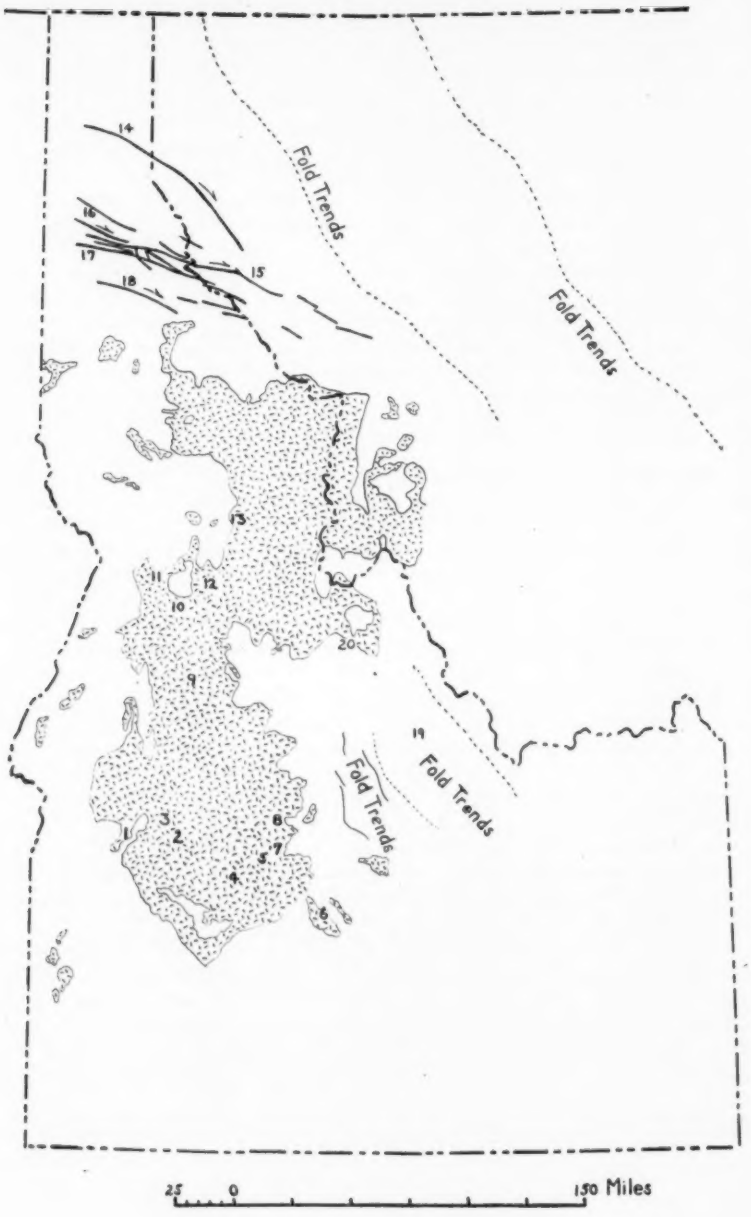
STRUCTURAL FAILURE OF THE IDAHO BATHOLITH.

Because of its massiveness and rigidity, the Idaho batholith could deform mostly by fracturing. The evidence of such deformation is found in faults and zones of faulting which for the most part have the precise structural relations demanded by the Laramide orogeny. Much of the failure was localized, the faults being grouped geographically and structurally into closely knit systems. Many of the structural zones are en echelon and are marked by intrusion and mineralization.

The characteristic faults are thrust, normal, and strike-slip, but these are not equally displayed. In some places the batholith failed mainly by thrust faulting, in other places by normal, and in still other places by strike-slip faulting. In general the latter denotes the dominant type of failure and has a greater geographic distribution than the others. It is generally accompanied by normal faulting and in some places the two are equally responsible in delineating the structural pattern. The various mining districts may have structural frames dominated by any one of the three or their combinations. Many of the districts not examined personally have structural trends like those with which the writer is familiar, but unfortunately published reports fail to class the faults or give their direction of movement. Only a few of them attempt a stress analysis and these seek causes within the batholith itself.

Thrust Faulting.—Failure by thrust faulting is particularly evident near the south margin of the exposed batholith and is well developed in Boise Basin and nearby districts (Fig. 1). Unlike those in the region of the Rocky Mountain trough, these thrust faults are of minor magnitude and commonly have lengths of less than a mile or two and in some places less than a thousand feet. Because of the absence of horizon markers, the amount of move-

[2] Ross, C. P.: Mesozoic and Tertiary granitic rocks in Idaho, Jour. Geology, vol. 36, pp. 623–693, 1928. Some features of the Idaho batholith, Rept. of XVI Session, Internat. Geol. Cong., pp. 369–383, 1936.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ment cannot be accurately measured but may range from a few feet in the case of the smaller faults to several hundred feet in those that are large. That the movement was thrust is indicated by vertical grooves and striations and the occurrence of ore bodies along the flatter parts of the fault.

The most striking feature of these faults is their trend, for characteristically the individual faults strike west-northwest to west, and, except possibly for those of more direct westerly trend, cut across all fractures known to be associated with the consolidation of the batholith. Those that strike about due west coincide closely in strike but not in dip with a prominent set of east-west joints formed during closing stages of batholithic emplacement. In places the jointing appears to have directed the later faulting and to have turned it from its more general northwesterly course.

With few known exceptions, the thrust faults dip to the southwest at angles of 30° to 60°.

This type of faulting is shown almost to perfection in Boise Basin.[3] The faults there are mineralized and as shown in Fig. 2 form a series of grouped parallel veins and lodes striking west-northwest and dipping southwest. Faulting of the same kind but generally of flatter dip is also characteristic of the Hailey Gold Belt (Fig. 1),[4] but the dip, unlike in Boise Basin, is 30°–60° NE. (Fig. 3). Some faults of this kind have also been recognized at Rocky Bar (Fig. 1), but the pattern is complicated by the presence of normal and strike-slip faults.[5]

The general west-northwest trend and southwest dip of the thrust faults indicate that the deforming forces were directed from the southwest. The opposite dip in the Hailey Gold Belt suggests the local development of the complementary set of thrust fractures.

Normal Faulting.—Normal faults are most conspicuous in regions dominated by strike-slip faulting, but, as at Rocky Bar,[6] are known to occur in the same structural zones as the thrust faults. The most notable concentration of normal faults so far observed is in the Atlanta district (Fig. 1),[7] where they form an integral part of a shear pattern (Fig. 4).

The normal faults range from several hundred to several thousand feet in

[3] Anderson, A. L.: Geology and ore deposits of Boise Basin, Idaho, U. S. Geol. Surv. Bull. 944-C, in press, 1947.

[4] Anderson, A. L. and Wagner, W. R.: A geologic reconnaissance of the Hailey Gold Belt, Blaine County, Idaho, Idaho Bur. Mines and Geol. Pamph. No. 76, pp. 1–26, 1946.

[5] Anderson, A. L.: Geology of the gold-bearing lodes of the Rocky Bar district, Elmore County, Idaho, Idaho Bur. Mines and Geol. Pamph. No. 65, pp. 11–12, 1943.

[6] Anderson, A. L.: Idaho Bur. Mines and Geol. Pamph. No. 65, op. cit., p. 11.

[7] Anderson, A. L.: Geology and ore deposits of the Atlanta district, Elmore County, Idaho, Idaho Bur. Mines and Geol. Pamph. No. 49, pp. 13–16, 1939.

FIG. 1. Index map showing the Idaho batholith, the direction of fold trends bordering the batholith, and the location of (1) Pearl-Horseshoe Bend district, (2) Boise Basin, (3) Quartzburg-Grimes Pass porphyry belt, (4) Rocky Bar district, (5) Atlanta district, (6) Hailey Gold Belt, (7) Vienna district, (8) Sawtooth district, (9) Yellow Pine district, (10) Warren district, (11) Florence district, (12) Dixie district, (13) Elk City district, (14) Hope fault, (15) Osburn fault, (16) Burnt Cabin fault, (17) Placer Creek fault, (18) St. Joe fault, (19) Blue Wing district, (20) Blackbird district.

length, but, as in the case of the thrust faults, actual amounts of displacement are indeterminate. Those at Atlanta are mineralized and form a system of closely parallel veins and lodes of west-northwest strike and steep northeast dip (Fig. 4). They occur on both sides of the Atlanta lode, the largest and most economically important lode of the group, which, unlike the others, strikes about N. 60° E. and dips almost vertically. This dominant lode, which is as

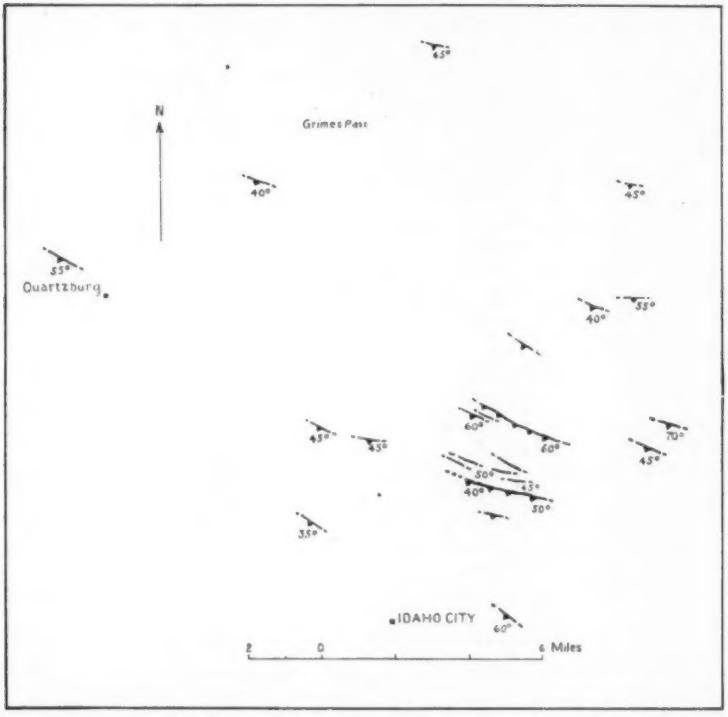

FIG. 2. Pattern of mineralized thrust faults in Boise Basin, Idaho.

much as 120 feet wide, occupies a prominent strike-slip fault zone. Some of the normal faults split off in a west-northwest direction as gash fractures which ordinarily do not persist outward for more than 200 feet. Most of the normal faults, however, are less directly associated with the strike-slip movement along the Atlanta lode.

The fault pattern at Atlanta is interpreted as one produced by horizontal shearing stresses with the strike-slip fault occupied by the Atlanta lode parallel to the shearing and the oblique normal faults formed under the tensional com-

FIG. 3. Pattern of mineralized thrust faults in the Hailey Gold Belt, Idaho.

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ponents of the stress.[8] Slickensides and grooves in the fractured ore and rock in and along the Atlanta lode show that the northwest side of the shear zone moved to the northeast with respect to the southeast side.

Some west and west-northwest normal faults and minor northeast strike-slip faults have been recognized at Rocky Bar,[9] but, outside of the Atlanta district, the most evident normal faults are those along major zones of shearing which localized Tertiary igneous intrusion, the normal faults directing dikes of west-northwest trend.

Strike-slip Faulting.—Although strike-slip faults have been recognized as components of the fault patterns in several of the mining districts of which the

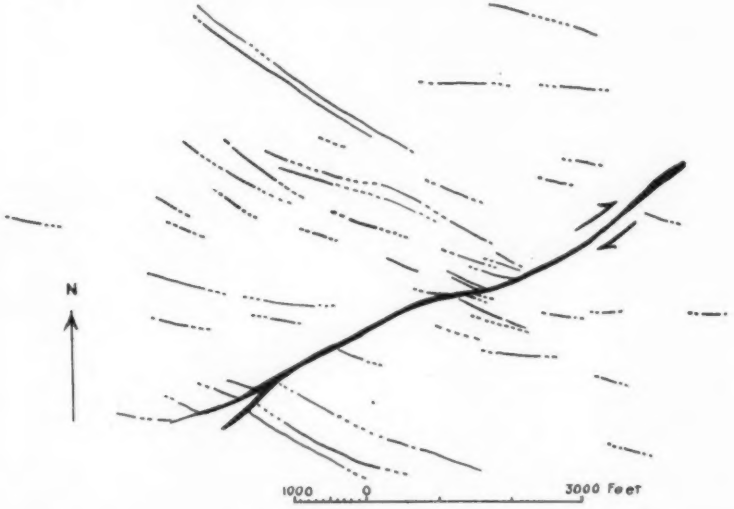

FIG. 4. Lode pattern in the Atlanta district, Idaho, with the Atlanta lode along a prominent northeast strike-slip fault and the other lodes along oblique west-northwest gash fractures and normal faults, mostly of steep northeast dip.

Atlanta is an outstanding example, they are much more prominent and apparently play a far more important role in localizing and directing igneous intrusion and controlling the belts of stocks and dikes in the batholith than in fixing vein and lode patterns. These strike-slip faults constitute major zones of structural weakness, identified readily by their contained intrusives. The zones are mostly grouped en echelon and extend for miles in a northeasterly direction. In general the larger intrusive bodies are elongated in the direction of the zone of structural weakness, but the smaller bodies tend to extend di-

[8] Anderson, A. L.: Idaho Bur. Mines and Geol. Pamph. No. 49, op. cit., p. 16.
[9] Anderson, A. L.: Idaho Bur. Mines and Geol. Pamph. No. 65, op. cit., p. 11.

agonally across, apparently occupying a west-northwest set of tensional fractures.

These structural zones have been invaded by two sets of intrusives, one believed to have been emplaced at the close of the Laramide disturbance in early Tertiary time, the other in mid-Tertiary time.[10] The early Tertiary magma was chiefly noritic but some differentiates of deep origin and of more silicic composition accompanied the norite. The mid-Tertiary injections range in composition from dacite porphyry to rhyolite with the greater part composed of quartz monzonite porphyry and rhyolite porphyry.

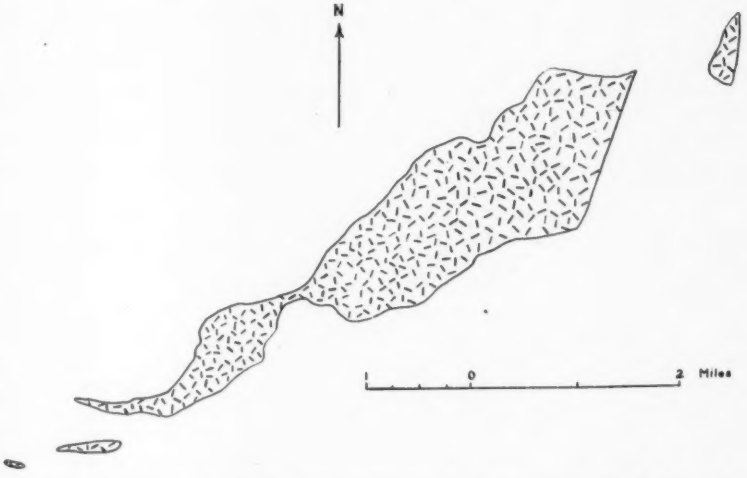

FIG. 5. Pattern of early Tertiary noritic stock and dikes in the Pearl-Horseshoe Bend district (porphyritic Miocene dikes omitted). Shows guidance of stock by northeast-trending zone of structural weakness, and of smaller bodies by subordinate west-northwest fractures.

Two of these structural zones have been studied in detail, many others have been recognized in reconnaissance. One of the better known extends through Pearl and Horseshoe Bend [11] near the southwest edge of the batholith (Fig. 1) and, as shown in Fig. 5, is marked by a body of noritic rock (hypersthene-augite-hornblende-biotite diorite) about 8 miles long, and from one-tenth to 1¼ miles wide, elongated in a N. 60° E. direction. At its southwest end the stock curves to the west-northwest, apparently controlled by fracturing of that direction. Two dikes just beyond the end of the stock also extend west-northwest. Failure along the same structural zone during the mid-Tertiary disturbance created many new fractures within and outside the noritic stock and

[10] Anderson, A. L.: U. S. Geol. Surv. Bull. 944-C, op. cit.

[11] Anderson, A. L.: Geology of the Pearl-Horseshoe Bend Gold Belt, Idaho Bur. Mines and Geol. Pamph. No. 41, pp. 6–11, 1934.

directed injections of lower Miocene magma. These younger intrusives have been omitted from Fig. 5, but they include a number of west-northwest trending dikes, mostly of dacite porphyry, which are largely clustered in the batholithic rock near the southwest end of the norite body, and many dikes of more silicic composition trending in a northeasterly direction in or across the stock.

The zone of structural weakness extending along the northern edge of Boise Basin and generally known as the Quartzburg-Grimes Pass "porphyry belt" [12] is of much greater magnitude than the one through Pearl and Horseshoe Bend. It has been traced in a N. 60° E. direction for more than 35 miles and is regarded as one of the major components of the regional structure.[13] It was invaded first by noritic magma and then by the younger mid-Tertiary stocks and dikes, its most distinctive markers. As shown in Fig. 6, some of the noritic magma was directed along west-northwest faults, but most of the magma was intruded along the main zone of structural weakness and is represented by a northeast-trending stock about 9 miles long and up to 1½ miles wide. During mid-Tertiary igneous activity, the stock was invaded by a large body of quartz monzonite porphyry and in places only minor remnants of the norite body remain.

There are other smaller belts of porphyries extending across or partly across Boise Basin [14] and many in the surrounding region including one near Rocky Bar,[15] another near Atlanta,[16] and one of large magnitude along the main Boise River.[17] Each of these trends about N. 60° E.

The early Tertiary intrusives show a more direct control by the shearing and the tensional fractures associated with the shearing than do the mid-Tertiary intrusives, which, though localized along these zones of structural weakness, are in fractures produced by somewhat differently applied forces. In most respects the early Tertiary stock and dike pattern is like the lode pattern in the Atlanta district but on a much larger scale and with particular emphasis on the horizontal shearing. The trend of the belts and the stocks and dikes within them, both parallel and oblique to the shearing, indicate shearing forces applied in a northeasterly direction, generally about N. 60° E.

Unclassified Faults.—Little attempt has been made in other mining districts, within the borders of the batholith, to classify the faults or place them in regional structural patterns. In most of these districts the prevailing trends are west-northwest, west, and northeast, showing a striking resemblance to the normal and strike-slip faults of the districts previously cited; but those who have studied the districts have been prone to consider the faults as primary structural features associated with the intrusion and consolidation of the Idaho batholith. Some recognize that movement along fractures was somewhat later, but none, except the writer, has considered that the Laramide orogeny had anything to do with forming the fractures and initiating the mineralization.

[12] Anderson, A. L.: U. S. Geol. Surv. Bull. 944-C, op. cit.

[13] Ross, C. P.: Some lode deposits in the northwestern part of the Boise Basin, Idaho, U. S. Geol. Surv. Bull. 846-D, p. 251, 1934.

[14] Anderson, A. L.: U. S. Geol. Surv. Bull. 944-C, op. cit.

[15] Anderson, A. L.: Idaho Bur. Mines and Geol. Pamph. No. 65, op. cit., pp. 6–11.

[16] Anderson, A. L.: Idaho Bur. Mines and Geol. Pamph. No. 49, op. cit., pp. 9–10, 16–17.

[17] Anderson, A. L.: U. S. Geol. Surv. Bull. 944-C, op. cit.

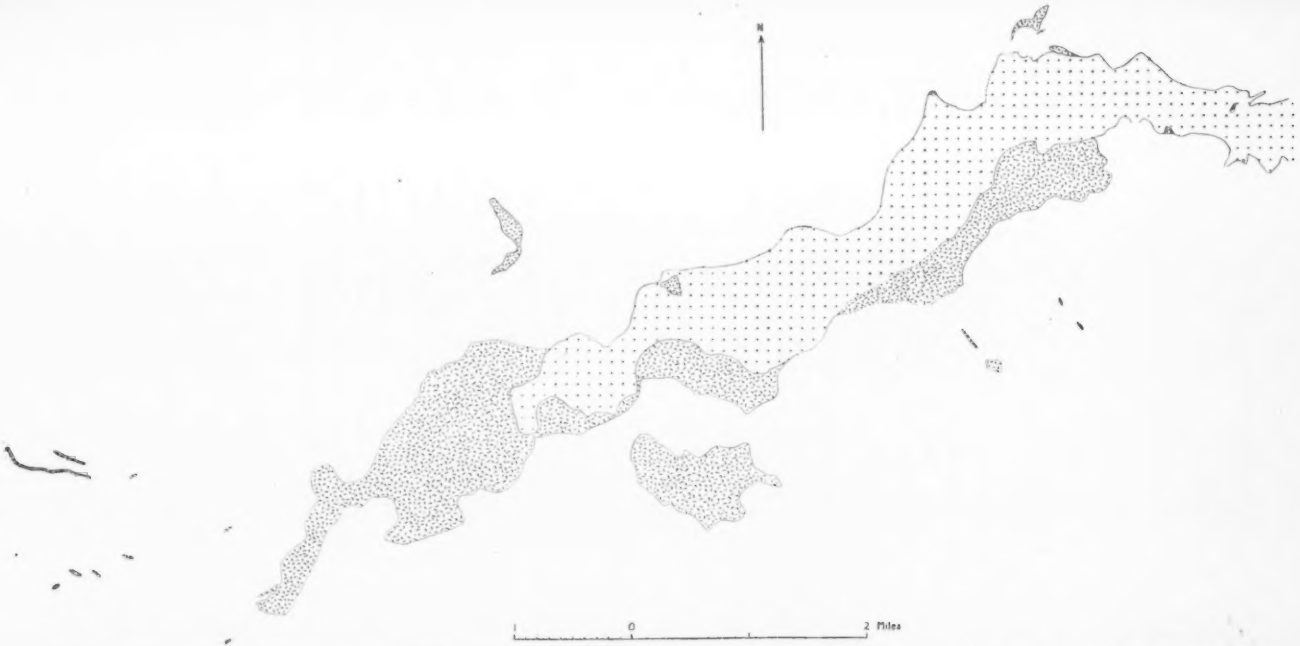

FIG. 6. Pattern of early Tertiary stocks and dikes and of a Miocene quartz monzonite porphyry stock (dot pattern) along the Quartzburg-Grimes Pass porphyry belt. Many of the smaller early Tertiary intrusives show guidance by northwest fractures, but the larger bodies show direction along the main northeast-trending zone of structural weakness. Much of the main early Tertiary stock has been destroyed by intrusion of the Miocene quartz monzonite porphyry which utilized a part of the same zone of structural weakness, which resulted from action of horizontal shearing stresses associated with differential transmission of stress through the batholith during the Laramide orogeny. A host of dacitic, quartz monzonitic, and rhyolitic porphyritic dikes of Miocene age has been omitted.

In the Vienna district (Fig. 1) not far east of Atlanta, the major fracturing is N. 65° W. and due west, about parallel to the dominant joint set, but the pre-mineral fissures there have been regarded as due in part to contraction during the cooling of the batholith and in part to later shearing and fracturing which perhaps resulted from readjustments occasioned by the intrusion.[18] This system of shearing apparently conforms with that in the Sawtooth district where the west set of joints is even more prominently developed, but the two lode systems—west and northwest—are later than the joints and have been uninfluenced by them.[19]

The Yellow Pine district (Fig. 1) in central Idaho has prominent zones of shearing, one due north and about parallel to and in about 2,000 feet from the contact of the batholith with a pendant of metamorphic rock, the other, N. 35° E., probably a genetically related offshoot with shear-plane relations.[20] The northeast shear zone is also about parallel to the curving contact of the huge roof pendant. The parallelism of the two-directional shearing with the curving contact of the batholith has been interpreted as indicative of the competency of the metamorphic rocks relative to the batholith rock in controlling the location and direction of the shearing in the district.[21] White disagrees with earlier workers in the district on the age of the mineralization which he regards as Tertiary rather than Mesozoic and therefore unrelated to the Idaho batholith.

In the Warren district (Fig. 1) a few miles northwest of Yellow Pine, the lode trends are between N. 70° W. and N. 70° E. and the dip between 45° S. and vertical.[22] These trends conform with a well-defined joint system and the veins have been interpreted as joint-fissure fillings, in part offset by a set of northwest fractures. The fracturing (apparently largely shearing) and the mineralization have been regarded as related genetically to the Idaho batholith.

Some of the joints in the Florence district toward the more northerly end of the batholith (Fig. 1) have been reported as having become fault planes during post-fracture movements and are mineralized.[23] The joints strike between N. 60° W. and N. 60° E. and dip steeply south; most of the lodes trend nearly east, between S. 75° E. and N. 80° E., a less conspicuous group between N. 45° E. and N. 65° E. The lodes dip mostly south at angles of 40° to 80°. No attempt was made to fit the lodes into a structural pattern nor to date them other than younger than the Idaho batholith and older than an erosion surface which is older than middle Miocene. Because of abundant vuggy and comb quartz, the deposits have been interpreted as formed at no great depth below the surface.[24]

[18] Ross, C. P.: The Vienna district, Blaine County, Idaho, Idaho Bur. Mines and Geol. Pamph. No. 21, pp. 9, 14, 16–17, 1927.

[19] Ballard, S. M.: Geology and ore deposits of the Alturas quadrangle, Blaine County, Idaho, Idaho Bur. Mines and Geol. Bull. 5, pp. 11, 16, 1922.

[20] White, D. E.: Antimony deposits of a part of the Yellow Pine district, Valley County, Idaho. A preliminary report, U. S. Geol. Surv. Bull. 922-I, pp. 256–258, 1940.

[21] White, D. E.: U. S. Geol. Surv. Bull. 922-I, op. cit., p. 258.

[22] Reed, J. C.: Geology and ore deposits of the Warren mining district, Idaho County, Idaho, Idaho Bur. Mines and Geol. Pamph. No. 45, pp. 20, 36–37, 1937.

[23] Reed, J. C.: Geology and ore deposits of the Florence mining districts, Idaho County, Idaho, Idaho Bur. Mines and Geol. Pamph. No. 46, p. 16, 1939.

[24] Reed, J. C.: Idaho Bur. Mines and Geol. Pamph. No. 46, op. cit., p. 29.

In the Elk City district in the north central part of the batholith (Fig. 1), the veins appear to be related structurally to a single vein system radially arranged in a zone less than 2 miles wide adjacent to the batholithic contact with apparent nearly right-angle relation to a linear schistosity. They have been interpreted as a set of cross joints normal to the stretching.[25] The veins strike N. 80° E. to N. 45° E., but it has been pointed out that the fractures could be the result of regional structural forces and not necessarily related to mineral orientation during flow. In the Buffalo Hump area (Fig. 1), the vein system and the veins within it trend about N. 10° E. and occupy a position at the crest of a large anticline of northwest trend, the veins dipping at angles greater than 60°, those in the western part to the west, and those in the eastern part, with one notable exception, to the east.[26] Gouge surfaces bounding the veins are reported commonly showing striations, which are nearly horizontal. Other veins of the region form less well-defined vein systems, but some trend west-northwest and others northeast. Because of evidence of shallow vein deposition throughout the region, it has been concluded that much of the batholith cover was eroded before mineralization, inferring that the emplacement of the batholith and the attendant mineralization extended over a very long period of time.[27]

In the Dixie district, which lies a few miles south of Elk City (Fig. 1), the veins form a single system striking about N. 55° W. and dipping 55° NE. to vertical, but they are arranged en echelon in northeast zones, suggesting a northeast structural control in addition to the northwest shearing.[28]

These various unclassified faults in scattered areas through the batholith have trends which conform with the normal and strike-slip faults in the districts studied by the writer. Some departures occur in the vicinity of large roof pendants, apparently because of local influences involving differences in rock competency in reorienting stresses, but otherwise there is everywhere a significant similarity of lode and vein patterns. Most of the structural interpretations have been made on the assumption that the fractures and their ores are genetically associated with the emplacement and consolidation of the Idaho batholith. The veins and lodes, however, are no different in substance and textural characteristics from those in Boise Basin and Rocky Bar, and, thus possessing the same metallogenetic stamp, probably came into existence at the same time, that is, at the close of the Laramide orogeny. The controlling fractures therefore are also probably related to that orogeny rather than to the forces associated with the emplacement and consolidation of the batholith.

SHEARING NORTH OF THE IDAHO BATHOLITH.

The fault pattern in the Belt rocks north of the Idaho batholith doesn't conform with either that in the Idaho batholith or in the rocks in the former

[25] Shenon, P. J. and Reed, J. C.: Geology and ore deposits of the Elk City, Orogrande, Buffalo Hump, and Ten Mile districts, Idaho County, Idaho, U. S. Geol. Surv. Circ. 9, pp. 25–26, 1934.

[26] Shenon, P. J. and Reed, J. C.: U. S. Geol. Surv. Circ. 9, op. cit., p. 26.

[27] Shenon, P. J. and Reed, J. C.: U. S. Geol. Surv. Circ. 9, op. cit., p. 30.

[28] Capps, S. R.: The Dixie placer district, Idaho, with notes on the lode mines by R. J. Roberts, Idaho Bur. Mines and Geol. Pamph. No. 48, p. 26, 1939.

Rocky Mountain geosyncline. Instead the pattern is dominated by great transverse faults of general west-northwest trend, the famous Osburn fault of the Coeur d'Alene district [29] and the Hope fault of the Clark Fork district [30] being outstanding examples. These, however, are but two of a number of more or less parallel transverse faults (Fig. 1), some of which are almost as large but, because of lesser associated mineralization, are not so well known. These faults are generally described as normal faults, but all of them appear to have a much greater horizontal component of movement, being strike-slip faults of the first order of magnitude. They dominate zones of complexly fractured rock and are the chief ore localizers of North Idaho.

Hope Fault.—The Hope is the most northerly of these great earth fractures. It has a more northwesterly trend than the others, averaging N. 55°–60° W., and dips steeply southwest. It closely parallels the lower course of the Clark Fork of the Columbia River for about 65 miles, then extends through the north arm of Pend Oreille Lake and through a notch across the Selkirk Mountains, giving it a total length of not less than 95 miles. It has an impressive vertical component of movement and stratigraphic throw, but the horizontal component is about 12 miles, the northeast side having been displaced southeast relative to the southwest side. Along the fault zone are many associated fault fractures—low-angle thrusts, high-angle reverse, high-angle normal, and two sets of strike-slip faults—all related to the Hope and resulting from the tensional and compressional components of the horizontal shearing stresses which produced the Hope.[31] The faulting, intrusion, and mineralization are closely related events and are regarded as products of the Laramide orogeny.[32]

Osburn Fault.—The Osburn fault of the Coeur d'Alene district is of even greater magnitude than the Hope and has been mapped for 90 miles east-southeast of Coeur d'Alene Lake (Fig. 1). Its length is probably much greater, for its course approximately coincides with an old valley extending from Spokane, Washington, to Deer Lodge, Montana, a distance of 300 miles.[33] Its course is N. 70°–80° W. and its dip is steeply south. Like the Hope, it appears to have a strike-slip component of movement of about 12 miles with an eastward shift of the north side relative to the south side.[34] It also has many associated faults of variable magnitude, some of which are mineralized. Igneous intrusion and mineralization in the Coeur d'Alene district are largely localized along the course of the Osburn fault.

Other Faults.—Other faults of similar kind but of lesser magnitude include the Burnt Cabin fault a few miles north of the Osburn, the Placer Creek fault just south of the Osburn, the St. Joe fault still farther south, and a number of

[29] Umpleby, J. B.: The Osburn fault, Jour. Geology, vol. 32, pp. 601–614, 1924.

[30] Calkins, F. C. and MacDonald, D. F.: A geological reconnaissance in Northern Idaho and Northwestern Montana, with notes on the economic geology, U. S. Geol. Surv. Bull. 384, pp. 52–55, 1909.

[31] Anderson, A. L.: Lead-silver deposits of the Clark Fork district, Bonner County, Idaho, U. S. Geol. Surv. Bull. 944-B, pp. 51–60, 1947.

[32] Anderson, A. L.: U. S. Geol. Surv. Bull. 944-B, op. cit., p. 60.

[33] Calkins, F. C. and Jones, E. L., Jr.: Economic geology of the region around Mullan, Idaho, and Saltese, Montana, U. S. Geol. Surv. Bull. 540, pp. 9, 16, 1913.

[34] Umpleby, J. B. and Jones, E. L., Jr.: Geology and ore deposits of Shoshone County, Idaho, U. S. Geol. Surv. Bull. 732, p. 12, 1923.

others, some of them close to the Osburn and some of them near the Idaho batholith and still undescribed. The Burnt Cabin fault [35] has a more northwesterly trend than the Osburn, which causes it to diverge therefrom. It has been traced for 30 miles. The Placer Creek fault [36] is one of great persistence. It lies about 6 miles from the Osburn, is about parallel to it, and has been traced for 60 miles. The zone of faulting along the St. Joe River, designated the St. Joe fault,[37] is probably more than 60 miles long. This and the Placer Creek fault as well show downthrow to the south and much horizontal shifting of the north side with respect to the south. Other faults have lengths of only a few miles. They all show a notable parallelism and with few exceptions dip south toward the apparent downthrow. Many have localized intrusion, and some, minor mineralization.

There are also faults which diverge from the strike-slip faults and tend to link one with another. Some of these may be associated fractures, but some are probably faults formed during the earlier Nevadian orogeny, which are now offset by the transverse faults.

DEFORMATION ALONG THE EAST SIDE OF THE IDAHO BATHOLITH.

The Idaho batholith was emplaced in rocks that had apparently just been folded, but significantly the strata bordering the batholith are more closely compressed, overturned, and broken than the remnants of the roof rocks and the strata some distance east of the contact.[38] Bordering the batholith the folds also conform rather closely in trend to the larger sinuosities of the contact, their average trend being about N. 15° W., whereas farther away the axes do not show this correspondence and trend about N. 35°–40° W. (Fig. 1), which is at a considerable angle to the nearly northerly trend for the batholith as a whole.

In the mineralized area in or near the border zone, the fault and lode patterns seem to be strongly influenced by the fold lines and prevailing trends are generally northwest about parallel to the fold axes, but in places there are transverse relationships, conforming closely to the east-west and northeast trends so characteristic of the batholithic area. The influence of the northwest folding on later fault trends may be more marked in the highly folded Paleozoic strata than in the more competent and less highly deformed Belt strata, either close to or distant from the batholith. In the Blue Wing district of Lemhi County (Fig. 1), which is some distance from the exposed batholith, the Belt strata have been deformed into a faulted anticlinal fold which localized intrusion of a small body of granite and also directed the mineralization. Most of the mineralized fractures are along the crest of the northwest-trending anticline and roughly parallel to it.[39] In the Blackbird district, also in Lemhi

[35] Anderson, A. L.: Geology and metalliferous deposits of Kootenai County, Idaho. Idaho Bur. Mines and Geol. Pamph. No. 53, p. 29, 1940.

[36] Umpleby, J. B. and Jones, E. L., Jr.: U. S. Geol. Surv. Bull. 540, op. cit., p. 14.

[37] Anderson, A. L.: Idaho Bur. Mines and Geol. Pamph. No. 53, op. cit., p. 29.

[38] Ross, C. P.: Some features of the Idaho batholith, Rept. of the XVI Session Internat. Geol. Congress, pp. 376–380, 1936.

[39] Callaghan, E. and Lemmon, D. W.: Tungsten resources of the Blue Wing district, Lemhi County, Idaho, U. S. Geol. Surv. Bull. 931-A, pp. 8–10, 1941.

County but close to the margin of the batholith, the Belt strata have been sheared in northwest, northeast, east, and north directions, largely independent of fold trends.[40]

INTERPRETATION AND CONCLUSIONS.

The trend lines of the deformed strata of the former Rocky Mountain geosyncline indicate that the forces during the Laramide orogeny acted from a southwesterly direction. In transmitting these forces the Idaho batholith was more or less extensively and complexly fractured. In places it was broken by thrust faults of minor magnitude and of general northwest trend, but the main failure took place along northeast zones of shearing aligned in the direction of the transmitted stresses. The thrust fractures apparently reflect the compressive components of the orogenic forces, the northeast zones of shearing with their complicated strike-slip and normal faults, the differential transmission of forces through the batholith into and influenced by conditions within the basement rocks and the Rocky Mountain trough. Large roof pendants of particularly competent rock and planes and zones of weakness developed during late stages in the emplacement of the batholith served locally to reorientate the stresses and cause minor departures in fracture patterns.

The batholith apparently also had a profound influence on the deformation of the Belt rocks for scores of miles beyond its north margin. Because of the crustal shortening by folding of the Belt strata, the rocks there were sheared around the rigid mass of the batholith and were broken by great transverse faults with large horizontal components of movement. These great faults were directed east-southeast oblique to the shear trends in the batholith and to trend lines of the trough. Thus the strata were shoved eastward along the strike-slip faults, the rocks on the north sides of the faults being forced southeast to compensate for the greater shortening progressively away from the north end of the batholith.

The more intense deformation of the strata on the east border of the batholith has been interpreted as imposed by the intrusion of the batholith of the earlier folds on its flanks.[41] It more likely resulted from the forces transmitted through the batholith into the folded rocks. These forces intensified the earlier Nevadian folding with local rearrangement of the trend lines to conform more closely with the contact of the batholith. The transmitted forces provoked some fracturing of the folded rocks, like that within the batholith, but they also produced fractures which show considerable guidance by earlier trend lines, in places almost completely so.

The shearing of the batholith and the rocks to the north, which has given rise to the main zones of structural weakness both within and outside the batholith, is the most important structural event associated locally with the Laramide orogeny. The great transverse strike-slip zones of faulting extending to deep magma sources facilitated and localized intrusion of magma at the close of the orogeny and provided escape for the genetically related mineralizing solutions.

[40] Anderson, A. L.: A preliminary report of the cobalt deposits in the Blackbird district, Lemhi County, Idaho, Idaho Bur. Mines and Geol. Pamph. No. 61, pp. 6–7, 1943.

[41] Ross, C. P.: Rept. of XVI Session Internat. Geol. Congress, op. cit., pp. 377–380.

From these deeply extending faults the solution spread upward into the various fractures near the surface and deposited ore. Later these zones of structural weakness had a profound influence in localizing deformation, intrusion, and mineralization during the mid-Tertiary crustal disturbance. The shearing of the batholith and adjacent rocks during the Laramide orogeny therefore was an event of great economic significance, for the zones of structural weakness dominated by the strike-slip faults prepared the setting for most of the ore deposits of Idaho.

The localization of the Tertiary intrusives and of the attendant mineralization along the strike-slip fault zones indicate that the strike-slip faults are the only ones that extended deeply enough to tap magmatic sources. These faults therefore exert a fundamental control on igneous activity and mineralization, probably in other places as well as in Idaho.

ACKNOWLEDGMENTS.

The writer wishes to acknowledge his indebtedness to his colleague, Professor C. M. Nevin, of Cornell University, for his helpful reading of the manuscript.

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AGE DETERMINATION OF QUARTZ VEINS AND PEGMATITES IN BRAZIL.

DJALMA GUIMARÃES.

CRITICAL ASPECTS OF AGE DETERMINATIONS.

RECENT geochemical researches have made it advisable to give further study to some of the ideas upon which the interpretation of geologic observations is based. In previous publications (4–8) [1] the author has examined some of these ideas, and in this paper extends his studies to the basis of the age determination of rocks by the determination of the ratios Pb/U or Pb/U + Th in their radioactive minerals.

It appears to have been assumed generally in the application of this method that all granitic rocks, whether apophyses or batholitic masses, have resulted from the freezing of an acid magma. When such rocks occur as dikes or extruded masses, as with granophyres, porphyries, and rhyolites, the age of the constituent minerals may reasonably and safely be considered as the same as that of the rock mass as a whole. Monazite, orthite (allanite) and other radioactive minerals found in such an environment offer the means for a reasonably accurate age determination.

However, it is unsafe to extend this method to pegmatites and similar granitic dikes unless a preliminary petrogenetic study is made. Great care should be taken in age determinations of batholitic masses of granites showing pegmatitic phases or coarse phacoidal structure, because recent findings indicate such rocks are palingenetic, so that it is difficult to tell how many stages of granitization are present in a given formation. For example, it is possible that conflicting radioactive age determinations in a given region may be due to pegmatite injection at different times.

Based on field observations as well as on the study of previous data, Johnston and Butler (2) have tried to get a satisfactory figure for the age of the quartz deposits in the quartz-producing areas of Brazil. They have found that in the northeastern and mideastern productive areas, the pegmatites cut Archean rocks. The partially pegmatitic deposits of Conquista (State of Bahia), of Teofilo Otoni (State of Minas Gerais) and of the State of Espirito Santo, are also in Archean rocks; the quartz veins of Mimoso and Xique-xique (State of Bahia), Cavalcanti, Cristalina and Piaus-Itaporé (State of Goyaz), as well as some of the deposits in the State of Minas Gerais, occur in Algonkian and Silurian (Bambuí Series) rocks. Broadly speaking, pegmatites in later formations turn into quartz veins, a fact suggesting post-Bambuí and pre-Devonian age, since no quartz veins nor pegmatites are to be found cutting Devonian strata. The authors state:

[1] Figures in parentheses indicate references in bibliography at end of paper.

This distribution appears to indicate a stratigraphic gradation between the deeply buried typical pegmatites, emplaced in Archean rocks, and the less deeply buried quartz veins of Central Minas Gerais, Bahia and Southern Goyaz, which occur in upper Algonkian and Silurian rocks. No quartz deposits are known in post-Silurian rocks although the upper part of the Paleozoic is fairly well represented in various parts of Brazil (2).

In other words, as Cambro-Silurian formations were eroded, the underlying pegmatitic zone (meso to kata-zone) was uncovered. In Minas Gerais, however, Algonkian areas containing metamorphic rocks either cut by pegmatites or showing lit-par-lit granitization, as at São João del Rey, Espera Feliz, southeastern Itamarandiba and other places, contain no quartz deposits.

From Central Minas Gerais northward, right on up to the mountainous regions formed by the eastern border of the Rio São Francisco's Silurian geosyncline (Serra Mineira and Serra do Cabral), Algonkian metamorphic rocks show an earlier stage of granitization than the last phase of regional metamorphism. Schists and quartzites that had been injected with pegmatites and percolated by acid magmatic residues underwent retromorphosis, turning into phyllonites. Both schistose rocks and pegmatites cutting them were sericitized and cut by the quartz veins referred and examined by Johnston and Butler.

The diamond deposits of Diamantina, north of Minas Gerais, are covered by these phyllonites and also cut by quartz veins.

Thus, Algonkian formations were affected by two phases of granitization: a pre-Silurian one, perhaps Proterozoic, and a post-Silurian. Quartz veins and a certain group of pegmatites, therefore, belong to the Caledonian cycle of Paleozoic diastrophism. Johnston and Butler's conclusions are in agreement with our early findings (4 to 8).

We must still consider the discrepancies in age determinations by the Pb/U or Pb/U + Th ratios referred to by Johnston and Butler.

Owing to the poor analytic accuracy of older methods for determining U and Th, errors may have arisen, but these are perhaps smaller than those made by geologists in interpreting the results.

Nevertheless, as calculations of ages may now be made based on the ratios of the lead isotopes to their parent elements (Th, AcU, UI) and also corrections applied to the PbU + Th ratio for any "common" Pb present using mass-spectrographic methods, when large differences in ages for the same or similar occurrences are found, investigation of the reasons therefor is necessary.

In an analytic study on radioactive minerals, Willer Florêncio, chemist of the "Instituto de Tecnologia Industrial do Estado de Minas Gerais," investigated the poor features of age determination of rocks by their radioactive minerals, emphasizing that this procedure implies the following assumptions (11):

(1) The time of the mineral's formation must agree with that of the remnant rock-forming minerals;
(2) The rock had a single genetic stage or physicochemical cycle of crystallization;

(3) The radioactive mineral has undergone no changes whatsoever (except atomic disintegration) since its crystallization.

Inasmuch as granitic pegmatites are the rocks used in most geochronological studies, and as their radioactive minerals are accessories, an accurate petrogenetic study is needed to prove that these assumptions are valid.

The latest researches on palingenesis and anatexis make it appear that granitic masses are largely the result of progressive granitization, and originate neither as the result of a single physico-chemical cycle nor from the consolidation of an acid magma. This latter process accounts only for dike-like masses of granite and for its eruptive equivalent—rhyolite.

Studies by the author on Brazilian pegmatites have shown recurrent granitization in the same dike; or rather that there are pegmatites connected with palingenetic granite (4–8). He has shown that there are calcio-sodic pegmatites (with oligoclase and albite), cutting rocks of the Minas and Itacolomi series (Algonkian), which later underwent granitization by acid solutions rich in potash and silica. This palingenesis produced microcline pegmatites with mica, beryl, monazite, xenotime, and other radioactive minerals.

In investigations by several authors, superposition of hydrothermal effects over pneumatolytic ones could be shown even in pegmatites of a single physico-chemical cycle of formation—which represents a variation, projected in time, of physico-chemical conditions. Hence, in the final stage of crystallization of a pegmatite, changes may take place in the earlier formed minerals.

My own investigations on rare minerals from pegmatites lead me to agree with the following findings by P. M. de Almeida Rolff (3):

> Blomstrandine-Priorite.—Euxenite-polycrase in the pegmatites of Lagoa dos Defuntos, at Cubati-Picui, suggests that such minerals are a result of alteration. Microlites from Alto Onça probably were derived from tantalates, altered by hydrothermal action at low temperature (pages 45 and 46).
>
> Microlite.—At Borborema, two specimens bear this name. One occurs at Alto Onça that appears to have been derived from a more complex tantalate, perhaps blomstrandine-priorite. It shows a yellowish-shade with reddish spots. It is dusty, porous and heavy. . . . At times, specimens are found with inclusions of the primitive mineral, surrounded by concentric zones of alteration. The physical properties of the fresh mineral suggest blomstrandine-priorite.
>
> Several different rare earth tantalates occurring in pegmatites from Terra Branca show concentric zones of yellowish-white alteration suggesting microlite. Alteration in these tantalates is not advanced: it starts next to the fracture and spreads over the crystalline mass. I believe this alteration process to be recent (page 47).

In a tantalite from the State of Paraiba the author checked the same microlite formation specified in the last instance. Polished and thin sections examined by reflected and transmitted light disclosed a system of transparent reticulated veinlets, in whose mesh were included angular fragments of tantalite. The mineral had obviously turned into microlite. I do not believe that weathering can provide the physico-chemical conditions needed to accomplish such a replacement process, and rather accept the original Rolff suggestion, that is, hydrothermal alteration.

Dana's System of Mineralogy, 1944 Edition, states on pages 615–616:

> Alter.—Uraninite alters easily. Presumably the invariable presence of UO_3 in the composition is due to alteration. Alteration zones are often well marked and this indicates that Th is most easily leached out, and U is less easily leached than Pb. This selective alteration sometimes offers serious difficulties in using the Pb/U ratio for age determination.

These considerations may well be extended to other uranium-bearing minerals, such as tantalates, columbates, titanates, etc.

Alteration is frequently made evident by a greater water content, a characteristic shared in common by all radioactive minerals. Seeing that water content could be beyond 4 percent and more than half the UO_2 turned into UO_3 with no appreciable external changes, no reliable test has hitherto been established for determining the status of alteration. Rare-earth elements can also replace other elements and leave apparently no traces of the substitution.

Replacement in pegmatites is much more common than most petrologists care to admit. Generally speaking, opposition to the acceptance of this process of mineral transformation rests in the meaning ascribed to the word "replacement." Nevertheless, bearing in mind the current views on the ionic constitution of crystals, the process is an ionic replacement that has taken place under favorable physico-chemical conditions. Among such conditions, I stress the tolerance shown by the ionic network of the primary mineral; ionic radius of active elements and their concentration in—or difference of concentration between—the surrounding solution and the solid phase represented by the mineral; the thermally induced electro-osmotic potential, and others.

Groups of tantalo-niobates represented by rare-earth and uranium-bearing minerals occur in isomorphous series where the phenomenon of ionic replacement can take place with either relatively minor modification of physico-chemical environment, or, more readily, when a new process of granitization is started by a new exo-magmatic effect.

In Table I analytical data are given for age determination of Brazilian radioactive minerals from several authors.

Some recorded analyses have been discarded due to the advanced status of decomposition of the specimen as disclosed by high water content. Probably erroneous conclusions are well emphasized by the polycrase analysis. To us, hydration appears rather a symptom of uranium migration, whose alkali compounds are more easily soluble—particularly in the presence of carbon dioxide—than those of lead. Hence, any metasomatic process will lower the uranium content while increasing that of lead. The contrary is true when uranium solutions act on other minerals (phosphates and silicates), since the resulting minerals will be poor in lead, thus giving low age values for the mother rock.

Age determination resting on the Pb/U and Pb/U + Th ratios must therefore be preceded by accurate petrogenetic investigation of the granitic host rock that bears the minerals considered. When the rock is either a palingenetic or a polygranitized one, all data should be duly checked by other procedures or rejected outright.

TABLE I.

Nr.	Mineral	Locality	H_2O	ThO_2	U	PbO	Approximate age in m. y.
1	Monazite	Divino de Ubá (Minas Gerais)	—	—	—	—	360
2	Samarskite	Divino de Ubá (Minas Gerais)	—	—	—	—	340
3	Samarskite	Divino de Ubá (Minas Gerais)	—	—	—	—	395
4	Annerodite	Rio Guanhães Sabinopolis (Minas Gerais)	—	—	—	—	352
5	Uraninite	Tibirí-Picuí (Paraiba)	0.68	—	78.54	5.12	445
6	Uraninite	Engenho Central Rio Branco (Minas Gerais)	1.22	—	78.02	5.71	498
7	Polycrase	Santa Clara Pomba (Minas Gerais)	—	—	—	—	546
8	Polycrase	Santa Clara Pomba (Minas Gerais)	2.04	5.22	5.49	0.64	603
9	Djalmaite	Fazenda da Posse Brejauba (Minas Gerais)	4.62	—	9.71	1.10	749
10	Polycrase	Santa Clara Pomba (Minas Gerais)	5.94	4.93	3.89	0.77	926

(1), (2), (3), C. N. Fenner.
(4), J. F. de Andrade Jr.
(5), Willer Florêncio.
(6), Willer Florêncio and Celso de Castro.
(7), Hess and Henderson.
(8), Henderson.
(9), (10), Willer Florêncio.

Monazite, however, possesses a far greater field of stability than most other U or Th minerals. Experience in the investigation of diaphtoritic rocks whose phyllonitization has resulted from retromorphosis of granitized schists of the Minas series, has proved that monazite is one of the minerals affording the greatest stability even when subject to hydrothermal action. In the sericitic phyllites of Diamantina (8) that derive from hydrothermal metamorphism of migmatites (lit-par-lit injected schists), perfect monazite crystals were found showing natural faces, while zircon had undergone malaconization and other phosphate minerals had either turned into concretions or hydrophosphates. Moreover, owing to its physical and optical properties, alteration in monazite can be easily ascertained, and it is possible to select clean crystals for analysis.

C. N. Fenner (9) analyzed two smarskite specimens from Divino de Ubá (Minas Gerais) whose average age values differ only 7.5 million years from that of monazite from the same pegmatite.

Although such figures may be more reliable, due to their concordance, age determination should be carried out preferably with monazite from different sources, along with a detailed investigation of its mother rock. Thus, all possible care will be taken to obviate any possibly valid objection.

It is apparent that careful petrographic field and laboratory studies of the host rock should accompany all future age determination of the radioactive minerals contained in them.

GEOCHEMICAL INTERPRETATION OF THE SHINKOLOBWE (KATANGA) PARAGENESIS AS RELATED TO THE CONCEPTS ADVANCED IN THIS PAPER.

The views laid down by Vernadsky (14) in the interpretation of geologic and mineralogic data of the Shinkolobwe deposit strengthen the author's contention regarding the determination of geological age through the mathematical interpretation of uranium atomic disintegration in function of time.

The significance of the subject justifies quotations from Vernadsky's work, which was edited under the auspices of Professor Cayeux, of the Collège de France.

Vernadsky, on a basis of the studies of Schoep, Thoreau and Trieu de Terdonck, showed that the Shinkolobwe deposit, in its paragenetic aspect, presents striking evidence of uranium lead migration.

"New and strange" mineral compounds obtained convey the certainty that *"the effects of a new and important phenomenon lie before us."* Although short of data on regional geology, he states that what is known allows definite conclusion. And he writes:

> Toutefois, ce qu'on sait suffit pour faire ressortir un phénomène singulier, et jusqu'à présent unique, dont l'étude approfondie serait d'une extrême importance. Le gisement du Katanga montre, pour la première fois, du plomb uranique pur en grandes, quantités, sous la forme de minéraux plombiques ne renfermant que l'isotope léger du plomb.

This fact alone would indicate that the uranium protominerals were affected by metasomatism long after their formation, and that, just as migration of lead has occurred, migration of uranium could have taken place, so that the elements thus released went to aid the constitution of such secondary compounds as uraninite. According to Van Aubel, the mineral found at Shinkolobwe and called uraninite is secondary.

Vernadsky says further: (14)

> Quelques-uns de ces minéraux secondaires—dont le plus important est la curite, uranate hydraté de plomb—forment quelquefois le mineral d'où le radium semble avoir été extrait. Le processus de formation du plomb uranique est certainement ancien, car le radiumm et l'uranium sont en équilibre radio-actif. Parmi les cinq minéraux plombiques observés jusqu'à présent, un seul était connu antérieurement; les quatre autres sont nouveaux.
>
> Tous sont d'origine hydrothermale, c'est-à-dire qu'ils proviennent des solutions aqueuses ascendentes dont la température et la pression sont assez élevées. *Ces solutions contiennent simultanément l'uranium et le plomb uranique, ce qui montre que ce dernier n'a pu être engendré par l'uranium avec lequel il est actuellement combiné.*

The Brazilian occurrences described in this paper resulted from the recurrence of granitizing acid magmatic residues that percolated through the peg-

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matites. The Pedro Espirita deposit of secondary uraniferous minerals shows conditions similar to the ore described by Vernadsky.

Obviously, objection to the method of age determination applies only to early granitic apophyses, principally of the continental Archeo-Proterozoic massif, where diastrophism was accompanied by deep magmatic activity. In such cases, if the idea of gradual granitization is admitted, the objection is valid. Yet, although unaware of the present author's hypothesis of gradual granitization, Vernadsky points out that a hydrothermal process in uraniferous pegmatite may alter all pre-existing equilibria:

My own studies on Brazilian (Caledonian) pegmatites have disclosed evidence of palingenesis and indicate great possibilities of migratory phenomena under both pneumatolytic and hydrothermal conditions. This is the interesting conclusion advanced by Vernadsky concerning the Shinkolobwe (Katanga) occurrence:

En résumé, Shinkolobwe représente la migration, par voie hydrothermale ascendente, d'atomes de plomb uranique, en masses importantes et très éloignées du lieu de leur genèse radio-active. Il s'agit là d'un mode de migration nettement différent de celui que nous avons décrit plus haut, à propos du radium et du mésothorium présents dans les eaux salées de formule Cl-Na-Ca.

PALINGENETIC PEGMATITES OF MINAS GERAIS AND THE MINERALS THEY YIELD.

Nazaré-São João del Rey.—Close to the station of Nazaré, municipality of São João el Rey, and precisely at mark 166.4 kms. (Rede Mineira Railway), a pegmatite dike occurs which has been previously reported (*7*, 15).

The dike crosses the railroad bed and the river (das Mortes), running parallel to it, and strikes about 70° NE, dipping 80° NW. The host rock is biotite-schist of the Minas series. Outcrops allow accurate observations along nearly 2 miles and the width ranges from 3 to 30 yards. Granulation varies as well as quantitative distribution of constituent minerals: microline, quartz, oligoclase, muscovite, spodumene and lepidolite. In places, clusters of larger crystals of cassiterite, spodumene and lepidolite are found. Spodumene crystals may attain over 4 inches in length.

With respect to microcline and quartz, oligoclase is idiomorphic and invariably of smaller size. Tectonic effects are evident in the abundance of crystals either fractured or exhibiting bent lamellae. The plagioclase contains an average of 25 percent of anorthite and may be enclosed in microline, sometimes in albitized form. Larger microcline crystals may include oligoclase, albite, quartz and relics of spodumene or lepidolite, and muscovite that envelopes residual spodumene. Cassiterite, which, together with quartz, constitutes venular or lenticular bodies, appears cracked and invaded by quartz. Tourmaline is relatively rare.

The manner wherein microcline includes other minerals, the replacement of spodumene by quartz and the formation of lepidolite, suggest two granitic stages of the rock, the first one marked by the presence of a calcio-sodic granitic dike. This association is common in pre-Devonian time, as we have reported in different papers on progressive granitization.

Santa Maria do Suassui.—In the District of Glucinio, muscovite-bearing pegmatites cross gneisses and schists or quartzites of the Minas series. Some form the famous Cruzeiro mine, and smaller mines are known as Sexta-Feira, Campinho, Aricanga and Safirão (13).

In a report in process of publication, Dr. Iphygenio Soares Coelho will describe these mica deposits and also an interesting occurrence of fibrous tourmaline. Some of his data he has kindly permitted me to use here.

The Cruzeiro pegmatite is composed of perthitic and microperthitic microcline, oligoclase, quartz, and muscovite. Oligoclase occurs in masses of cataclastic structure, and shows bent lamellar crystals or irregular crystals enclosed in microcline.

Giant microcline crystals may contain inclusions of other pegmatite elements, such as spodumene, beryl, lepidolite, cassiterite in octahedral crystals, columbite and gummite.

Most of the dark green or nearly black tourmalines appear cracked parallel to the base and bear an interesting phenomenon of discoloration. A single crystal may possess two colors, being part green and part rose-red (rubellite). Red tourmaline is sometimes cavernous, and shows fibrous structure in certain zones of the prism closely analogous to asbestos. Microscopic and chemical tests of this structure disclose colorless, somewhat pliant, very fine fibers. Corrosion of rubellite and bleaching and transformation from green into red tourmaline obviously results from the migration of iron content.

Since the Cruzeiro pegmatite was formed in two stages, the late stage characterized by the percolation of granitic potassium emanations and the formation of microcline by replacement of plagioclase, together with the transformation of spodumene into lepidolite and the crystallization of cassiterite, it is, therefore, likely that the residual solutions of the latter stage were fluorine-bearing, which should account for the iron migration in tourmaline, as well as for the corrosion and change into colorless asbestos-like specimens.

Governador Valadares.—Pegmatites of this area are particularly rich in mica, semi-precious stones, rare earths and uranium-bearing minerals.

The author inspected a collection of rare specimens owned by Dr. Julio Soares. Some were from the pegmatite of a locality called Pedro Espirita (headwaters of Corrego Onça), while others came from the Golconda deposit. Their interesting features are recorded below.

Spodumene (heddenite), beryl, quartz, columbite, tourmaline and topaz occur in large crystals, whereas cassiterite, phenacite, garnet and apatite are found only in centimetric specimens. Most of them lined vugs or geodes, and considering their association with high quartz that at times appears bi-terminated, it would seem as though they formed under hydrothermal conditions, whereas the corroded aspect of others induces the belief that they must have been redissolved.

(a) Quartz.—Seldom smoky, in crystals showing a prevalence of pyramid faces and of "m" faces with smaller area. Hyaline specimens are often flattened by the exaggerated growth of two opposite and parallel "m" faces. Prismatic and bi-terminated crystals are common.

(b) Beryl.—Of rose color (morganite), clear, studded with tourmaline.

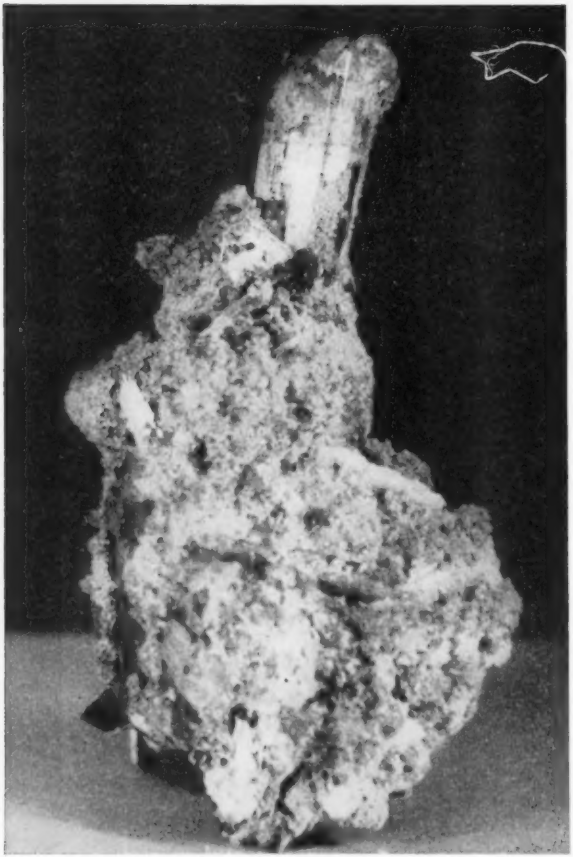
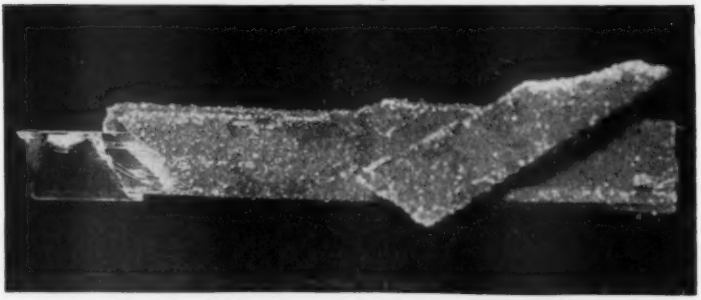


FIG. 1. Aggregation of red, green, green gray and colorless, fibrous tourmaline cemented by lepidolite. In the upper end, a large tourmaline specimen with a cavernous and fibrous core. Pedro Espirita (Governador Valadares) Minas Gerais. ⅓ natural size. Photo by Lab. Fotografico do I. T. I. de Minas Gerais.

Aquamarine and green blue specimens were also found. A morganite crystal exhibited the following faces: a(1010), s(1121), v(2131) and c(0001). Beryl also occurs in greenish blue irregular masses and in spongelike specimens of pale blue tinge.

(c) Apatite.—In centimeter crystals, transparent, rose colored. Faces a(1010), b(1120) and c(0001) were identified.

(d) Garnet.—Almandite generally has corroded faces.



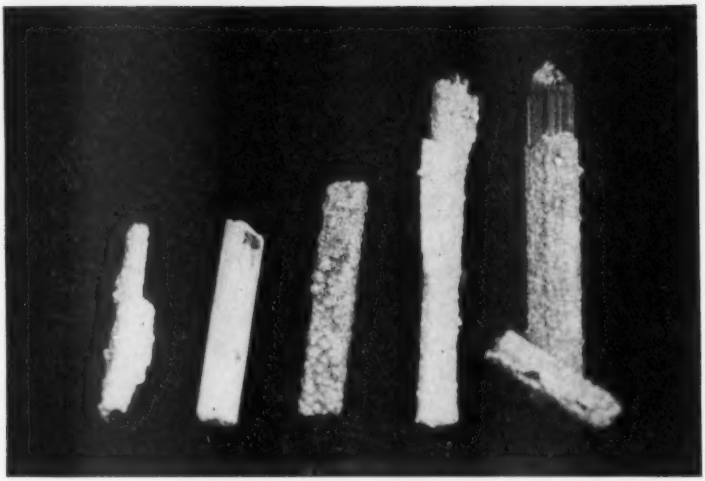


FIG. 2. (Upper) Lepidolite sheath enclosing spodumene. Pedro Espirita (Governador Valadares) Minas Gerais. ⅕ natural size. Photo by Lab. Fotografico do I. T. I. de Minas Gerais.

FIG. 3. (Lower) Tourmaline crystals covered by lepidolite layer. Pedro Espirita (Governador Valadares) Minas Gerais. ⅕ natural size. Photo by Lab. Fotografico do I. T. I. de Minas Gerais.

(e) Spodumene.—Frequent in the Pedro Espirita pegmatite, found in long and tabular prisms, clear, either colorless or slightly green. Large kunzite crystals are there, too. Corrosion patterns are common in prismatic faces, and frequently spodumene is inclosed in a lepidolite sheath as shown in Fig. 2.

(f) Tourmaline.—It is found in a variety of colors: green black, dark green, rose, blue green, gray blue, colorless and red (rubellite). Most interesting are the specimens partly or wholly covered with a lepidolite crust (Fig. 3). Tourmaline prisms of different sizes in dark green to red compose fine

looking clusters. Remarkable is the corrosion exhibited by the red crystals, some of which have been changed into colorless asbestos-like specimens.

Analogous material from the Cruzeiro mine (Santa Maria de Suassuí) was investigated by Dr. Iphygenio Soares Coelho who inclines to the view that such structural transformation resulted from a process of alteration involving the migration of Fe and Mn ions. The present author's investigations of tourmalines from Governador Valadares pegmatites confirm Dr. Coehlo's opinion.

Several bi- or multi-colored specimens were examined, whose dark green sections never exhibit the cavernous or spongelike structure so peculiar to rubellite. In addition, rubellite often presents a colorless zone of transition to the green one. Some centimeter crystals show a fibrous and colorless core inclosed in a homogeneous green crust.

Corrosion of rubellite proceeded in two directions: accompanying the cracks parallel to the base of the prism, and along the c axis. In the first case, after alteration into micaceous mineral, corrosion continues in the axial direction, and forms cavities where needle-like relics of red or colorless tourmaline are located. These cavities may be filled with mica, or with lepidolite and quartz. The second case produces a fibrous structure with capillary interspaces, as well as very small openings or tubes of varying section and length along the (0001) fracture. Products of transformation such as sericite, lepidolite and quartz, fill the cavities where irregularly shaped remnants of green tourmaline are also present.

Obviously green tourmalines changed color prior to transformation into micaceous substance. Analyses by Dr. Iphygenio Soares Coelho[2] indicate a nearly total loss of iron, together with a definite decrease of manganese content, while alkali component increases over the usual amount found in green or black tourmalines.

Cavernous or spongelike zones of rubellite may contain bunches of colorless fibers whose refractive indexes are quite similar to the asbestos-like tourmaline that resulted from the recrystallization of green or green black originals. Thus colorless fibers from a green black crystal showed the following indexes: $\epsilon = 1{,}619$, and $\omega = 1{,}635$.

Thus, upon examining the transformation of spodumene and tourmaline into lithia mica, the inference emerges that migration of iron and manganese must have preceded the lepidolite-forming hydrothermal process. Deposition of lepidolite over tourmaline, spodumene, microcline, albite, oligoclase and quartz, provides plain evidence that its formation must be simultaneous with the final quartz crystallizing stage. A great many pyramid terminated quartz crystals and vug lining clusters exhibit incrustations of radiating scales of lepidolite.

If rubellite results from migration of iron, in a pre-hydrothermal stage, under the influence of fluorine contained in solutions poor in iron, there was a difference in concentration of those elements between the solid phase, represented by tourmaline, and the liquid phase of the residual magmatic liquid.

[2] To appear shortly in the journal "Mineração e Metalurgia" of Rio de Janeiro.

The solubility of Fe in fluorhydric solutions, the small difference between Li (0, 78Å) and Fe″ (0, 83Å) ionic radii, and the difference of concentration of elements in the two phases, constitute the factors of ionic replacement.

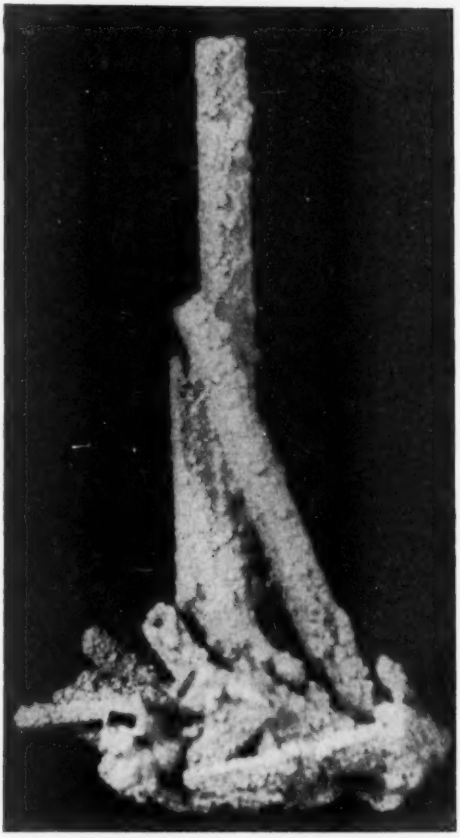


FIG. 4. Crustification of yellow lepidolite over spodumene. Pedro Espirita (Governador Valadares) Minas Gerais. ⅝ natural size. Photo by Lab. Fotografico do I. T. I. de Minas Gerais.

Transformation of green or green-black into fibrous colorless tourmaline is rendered easier by the arrangement of the cations of its crystalline network and indicates a wider spacing in the Si-Al-O chains. More advanced corrosion represented by the profusion of hollow spots and tubular notches along

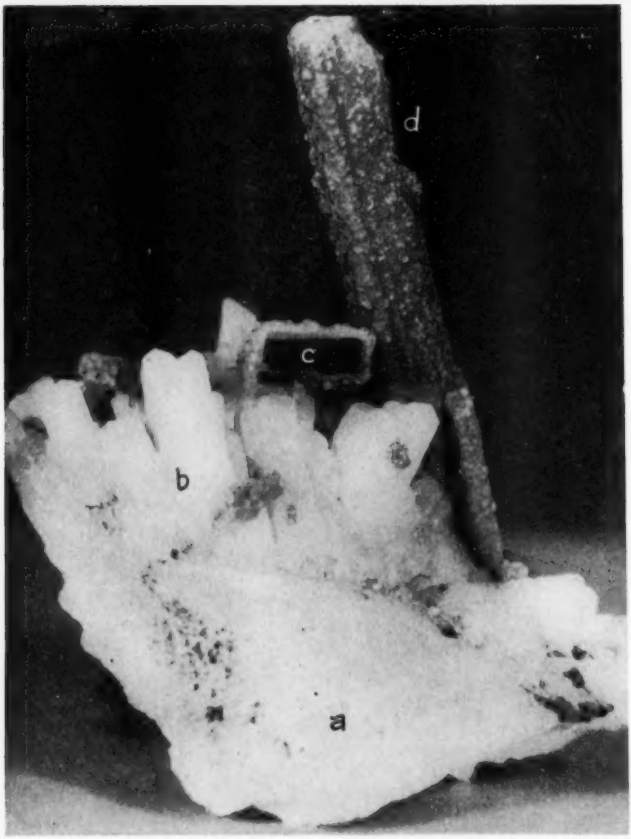


FIG. 5. (a) Microcline; (b) albite cluster; (c) lepidolite spodumene-enclosing sheath, the crystal lying in horizontal position; (d) tourmaline wholly covered by lepidolite crust. Golconda (Governador Valadares) Minas Gerais. ⅓ natural size. Photo by Lab. Fotografico do I. T. I. de Minas Gerais.

the prism seems to be explained effectively by the existence of greater facilities for the migration of cations in the c axis direction.

Sodium (0, 98Å) could replace iron and manganese (0, 91Å) as well, since the difference in their ionic radii is far less than 25 percent.

(g) Albite-oligoclase.—Large albite oligoclase crystals are found close to, or lying in, the aforesaid vugs, that at times are studded with quartz and lepidolite. Albite also forms clusters embedded on tabular milky microcline specimens of varying size (Fig. 5).

(h) Lepidolite.—In tiny flakes that compose radial assemblages of spherical shape, studding other minerals. In color it ranges from a soiled, yellowish white, to red and purple. Association is with spodumene, tourmaline, quartz, microcline and albite oligoclase.

Figs. 2, 3, 4 and 5 show spodumene and tourmaline crystals so thoroughly enclosed by lepidolite as to make a virtual sheath for them. Taking into account the existence of semi-dissolved spodumene (Fig. 6) lepidolite seems to result from its hydrothermal transformation.

(i) Gummite.—Gummite was found as the product of hydrothermal transformation of uraniferous minerals. In Dana's System of Mineralogy it is stated:

> The gummite that occurs as an alteration of uraninite in pegmatites appears to have been formed by the action of late stage hydrothermal solutions rather than by weathering processes.

(j) Microcline.—Found principally in perthitic and microperthitic giant specimens. Such structure has been regarded as indication of microcline re-

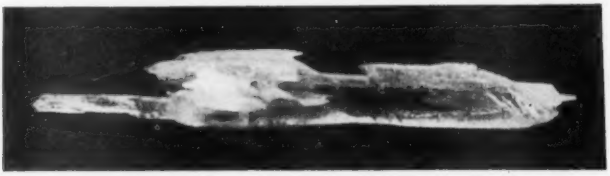


FIG. 6. Corroded spodumene. Pedro Espirita (Governador Valadares) Minas Gerais. ½ natural size. Photo by Lab. Fotografico do I. T. I. de Minas Gerais.

placement by albite. Investigations by the author confirm that it would rather indicate plagioclase substitution by microcline, since plagioclase is included in the form of oddly contoured remnants of more or less advanced albitization. Although the ionic radius of K is greater than Na, the substitution may be facilitated by the closeness of the albite crystalline lattice. This mineral possesses 49.90 percent of voids (16).

In alkaline solution, albite is more stable and replaces microcline in the final stage of pegmatite formation.

(k) Topaz.—Generally blue. When devoid of natural prism faces, it is often mistaken for aquamarine (blue beryl), unless one recognizes at once its appreciably greater density.

We can thus conclude that Pedro Espirita pegmatite grew largely in consequence of replacement of constituent elements of older rocks, and probably of the host rock itself. This consists of a complex of schists (amphibole schists and biotite-schists) more or less intensively gneissified by calciosodic granitic injections, that is, of mica schists with migmatite intercalations.

PEGMATITES OF NORTHERN BRAZIL.

The most comprehensive study of northeastern pegmatites is that of W. D. Johnston, Jr. (17). His morphologic, paragenetic and geographic data related to actual knowledge of regional petrology allow a few inferences that would support the thesis defended by the present author.

Additional petrographic data would be invaluable, particularly if arising from research in microcline and acid plagioclase, and a petrographic study of the surrounding rocks would also be important.

From the morphologic standpoint, the ideal section by Johnston should be regarded as basic for the genetic study of heterogeneous pegmatites. So much so, that in Divino de Ubá (Minas Gerais), the present author has found zonal arrangement and distribution of radioactive minerals (samarskite and monazite) precisely the same as outlined by Johnston. Fig. 7 shows an ideal pegmatite section and its four zones, after that author.

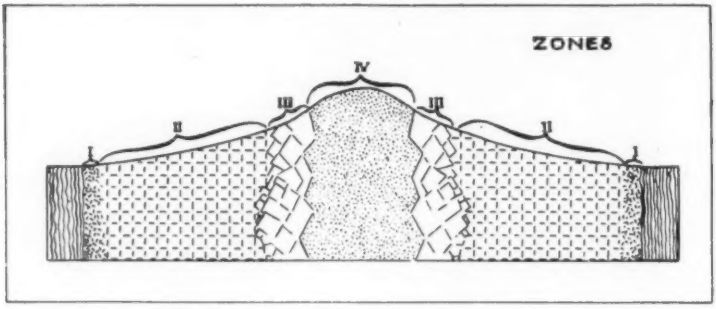


FIG. 7. Generalized sketch of a heterogeneous pegmatite showing the four zones. I, Muscovite; II, quartz, feldspar and muscovite; III, large crystals of feldspar; IV, quartz core. After W. D. Johnston, Jr.

In the initial stage of formation (zones I and II) replacement of microcline by albite would seem unlikely, since conditions favor microcline crystallization as a whole. Furthermore, the presence of fluorine and boron, as witnessed by tourmaline, indicates that in the early stage of the magma the residual solution was acid.

Formation of muscovite confirms such an assumption—a logical inference from the Johnston paragenetic diagram.

In other pegmatites, microscopic research revealed inclusions of plagioclase in positions dissimilar and discordant with a definite crystallographic arrangement. Inclusions generally exhibit an irregular contour and albitized periphery; the core is blurred and sometimes altered into very fine sericite scales (Nazaré pegmatite).

Therefore, replacement of plagioclase (oftener oligoclase) by microcline is clear.

Survival of albite in the guise of perthitic inclusions must be ascribed to its wide range of stability.

Most of the pegmatites studied by Johnston occur in mica schists and therefore evidence of two genetic stages is not so obvious as in other areas. This is why the late stage hydrothermal effect, that marks the decline of magmatic activity, is found to possess minor significance.

The manner wherein spodumene suggests pre-hydrothermal conditions can be inferred from this excerpt by Johnston (17):

> As shown in Almeida's map of Seridozinho (Fig. 31) the spodumene occurs in zone III and in the peripheral part of zone IV. Likewise at Alto Marimbondo (Pl. 4, Fig. 2), spodumene is found in both zones III and IV. . . . Lepidolite is rare in Picui-Parelhas areas, being found principally at Alto Boqueirão. It is abundant in some Ceará pegmatites, notably at Lago do Brito, near Cristais and Bolinha, near Quixeramobim. In the latter pegmatite it occurs in characteristic association with green and red tourmaline.

The last sentence is in agreement with the Pedro Espirita and Golconda (Minas Gerais) lepidolite occurrences. Concomitant with the nature of the host rock, this constitutes evidence whereby the palingenetic hypothesis of certain pegmatites is strengthened.

As for the Quixeramobim-Cachoeira (Ceará) area, Johnston (17) writes:

> The area includes parts of the municipalities of Quixeramobim and Cachoeira (Fig. 3). It is a region of low relief wherein the most conspicuous topographic elements are monadnocks of granitized schists. The country rock is a quartz-mica schist that in places has been granitized and assumes a gneissic aspect. Intercalated in the schists are beds of quartzite and marble.

In previous papers (4, 5, 15) it is pointed out that sedimentary rocks of the Minas series (Algonkian) have been granitized in the Penokean diastrophic cycle. The Ceará series, of equal age, was probably granitized during the same cycle. Johnston's studies on the scheelite from Paraiba and Rio Grande do Norte attest the process of Penokean granitization of the Seridó mica schists whose age is the same as the Ceará series.

The deposits consist of calcareous strata, beds and lenses more or less metamorphosed into masses of tactite and amphibolite, intercalated within mica schists that in places appear granitized.

The metamorphic rocks are crossed by pegmatite dikes that, in Johnston's view, would not seem responsible for the tungsten-bearing mineralization. His description and geologic section reveal a tectonic effect that caused folding, shearing and cataclases so extreme as to compel the admission of a diastrophic stage prior to the Caledonian one.

Folded mica schists and calcareous strata are crossed by pegmatite dikes exhibiting generally no tectonic effect. Regarding the Salgadinho deposit at Caicó (Rio Grande do Norte) Johnston and Moacyr de Vasconcelos (19) say:

> The mine consists of several small open cuts along a contact between granitic gneiss and mica schist. The schist is cut by a network of small quartz veins carrying garnet, epidote and some scheelite. *As both the granite gneiss and the schist*

have the same schistosity, i.e. a platy element, parallel to the contact, it appears most likely that schistosity was imposed upon both rocks at the same time.

Previous studies by the present author (4, 5, 15) strengthen the conviction that the Brazilian complex was subject to no additional mountain building diastrophism of post-Devonian age, so that the final stage must have been Caledonian. Thence, the supposed Caledonian pegmatites cutting the Ceará and Seridó rocks should disclose no tectonic evidence of tangential stress. It follows that these rocks witnessed two granitizing stages: Penokean and Caledonian.

Earlier petrographic studies (4, 5, 15, 18) show that the granitized schists of the Minas and Ceará series contain alkaline feldspar and plagioclase. It appears that many pegmatites grow laterally by replacement of the component elements of granitized schists when schists constitute the host rock and they have also grown at the expense of Penokean pegmatites. In this connection Johnston reports the suggestive occurrence of giant biotite crystals in Zone II.

Thus, it does not seem probable that the large pegmatite dikes have been formed by simple fracture filling. Furthermore, with variation of physico-chemical conditions, we might expect the replacement of certain minerals whose stability is most easily affected by variation in pressure, temperature and the composition of the residual magmatic solutions.

Furthermore, if, after a tectonic displacement, the crystallized parts of pegmatite were percolated by hydrothermal solutions, equilibrium of minerals of pre-hydrothermal formation located in zone III would be affected as well. The solutions would be produced either by falling off of energy activity or by the onset of a new magmatic cycle.

This is the case of uraniferous minerals that in zone III appear to be transformed into gummite, according to Johnston:

> Uranium Minerals.—A small quantity of uraninite (pitchblende) has been found in zone III in Xique-xique, Boqueirão and a few other altos. It occurs in rounded masses, generally small, surrounded by yellow, orange and green alteration products of undetermined composition: but provisionally called gummite. The largest specimen obtained was from Alto Xique-xique and weighed about 50 grams. Under ultraviolet light occasional masses of green fluorescent uranium minerals are seen. The amount of contained UO_3 in these pegmatites, however, is small. Many pegmatites contain chalcedony with the yellow green fluorescent characteristic of traces of contained uranium.

Evidence of minor tectonic displacements that occurred during pegmatite formation is found in the fracturing of tourmaline and beryl of zone III (ibid., page 1034). Chalcedony bears witness of hydrothermal effects. An analogous occurrence was described by Willer Florêncio and J. Costa Ribeiro in the Moeda Tunnel of the Central Railway, in the vicinity of Moeda (Minas Gerais). Gneissic rocks are there thickly injected with pegmatite veins of lenticular shape. Along fissures and diaclases in the gneiss, uranium-bearing chalcedony crusts and fluorescent opal can be obtained. An hydrated phosphate of uranium was also found as a secondary mineral. Although the uranium protomineral has not been located as yet, the occurrence obviously indicates the migration of this element.

CONCLUSION.

Should the concept of progressive granitization be accepted, *i.e.* if the recurrence of diastrophic movement in a region, with consequent deep magmatic activity, can generate acid magmatic residues, then palingenesis will be a major process in mineral transformation. Thus, some accessory minerals will be attacked metasomatically by acid residual solutions and certain component elements will migrate to lower temperature zones, where they will combine to form other accessory minerals.

Examples might be cited of aplitic pegmatites and granitic apophyses that were attacked by new granitic emanations rich in K, Fl and SiO_2. Whatever was the geological level of the present day outcrop at the time the pegmatite dike was attacked by a new phase granitization, *i.e.* whatever the distance from the magmatic focus, it is evident that the physico-chemical conditions may differ from those prevailing during a previous stage of granitization. Thus, the stability of many minerals of old pegmatites (Proterozoic in Brazil) might have suffered modification, as was the case of spodumene altered to lepidolite, tourmaline that was bleached or replaced by the asbestos-like material. As has been shown in the pegmatites of Pedro Espirita and Golconda, the formation of lepidolite and the migration of Fe^{++} in tourmaline, indicating the presence of fluorine, should lead us to seek a metasomatic process under conditions ranging from pneumatolytic to hydrothermal.

In resumé, the hypothesis formulating the migration of uranium and lead in the palingenetic or hydrothermally altered pegmatites, finds support in field observations in Brazil, and the process suggested by Vernadsky for the Shinkolobwe, Katanga, deposits may be equally applicable to pre-Cambrian uraniferous pegmatites in other parts of the world.

ACKNOWLEDGMENT.

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BELO HORIZONTE (MINAS GERAIS), BRAZIL,
Dec. 20, 1947.

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SYNTHESIS OF SOME SULPHARSENITES OF SILVER IN ALKALI SULPHIDE SOLUTIONS.

RENÉ BÉLAND.

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ABSTRACT.

Smithite ($Ag_2S.As_2S_3$), proustite and xanthoconite ($3Ag_2A.As_2S_3$), wire silver, and argentite were prepared in concentrated alkali sulphide solutions at temperatures below 500° C. and pressures below 900 atmospheres. The solutions were found to be chemically compatible with the gangue minerals found in epithermal silver veins. Therefore, the principal carriers for primary ruby silver ores are thought to be alkali sulphide solutions. The experimental results may explain some features of primary silver ores.

INTRODUCTION.

The Alkali Sulphide Theory of Ore Deposition.—The hydrosynthesis of silver sulpharsenites is part of a program of research carried on at the University of Toronto (Canada) to test qualitatively the alkali sulphide theory of ore deposition (27).[1] An outline of the theory and its observational and experimental bases has been published by F. G. Smith (26). To the arguments already presented may be added the following consideration. From experiments on the H_2S content on the Vosges granites and several diabases, Armand Gautier (8) concluded that these rocks contained traces (0.003 to 0.05 percent) of sulphosilicates analogous to lazurite ($3NaAlSiO_4.Na_2S$). A freezing granite could thus not only be in equilibrium with a solution containing alkali sulphides but could also retain some of the alkali sulphides, as

[1] Numbers in parentheses refer to the Bibliography at end of paper.

copper slags retain some sulphur as CaS after separation of the sulphide matte (Wanjukoff 1912).

Previous Work.—According to the alkali sulphide theory, silver should be carried in the ore bearing fluid as a soluble thioargentite of potassium or sodium. Similarly, arsenic should be present as sodium or potassium sulpharsenites. Alkali thioargentites and sulpharsenites have been isolated by Ditte (6) and their existence need not be postulated.

Silver sulpharsenites are easily precipitated by adding silver ions to alkaline thioarsenite solutions. Such precipitates are brownish cryptocrystalline mixtures of several silver-arsenic sulphides. Even salts such as $K_xAg_{(3-x)}$. AsS_3 are possible (19). Brown to red mixtures of that sort have been obtained by numerous workers since Berzelius (2) and are not artificial minerals although their overall composition may approximate the known ruby silvers.

H. de Sénarmont (21) and F. G. Smith (24) crystallized proustite and pyrargyrite from hot alkaline sulphidic solutions under pressure. Jaeger and van Klooster (11) obtained pyrargyrite crystals in sodium sulphide solutions. Artificial xanthoconite and smithite had never been produced by wet methods when the present work was undertaken (1944).

EXPERIMENTS.

Plan.—According to the alkali sulphide theory of ore deposition, sodium or potassium polysulphide solutions containing silver and arsenic should, when cooled from say 500° C. to room temperature, yield silver sulpharsenites identical with the natural ruby silvers. Therefore, the only chemicals used in the following syntheses were: distilled water, $Na_2S.9H_2O$ crystals, freshly prepared K_2S, pure sulphur, metallic silver (in wire form) and metallic arsenic. These reagents were mixed in various proportions, heated to 400° C. in a steel bomb (28) and cooled to room temperature in 8 to 12 hours. Crystals of synthetic ruby silvers were picked from the cooled charges under a binocular microscope. Professor M. A. Peacock of the University of Toronto, and his assistants, kindly identified the crystals by means of goniometric measurements and X-ray photographs, and prepared descriptions which are published elsewhere by Peacock (17, 18). Qualitative chemical tests were also made on the residual solutions.

Temperatures were measured with an accuracy of $\pm 5°$ C. by means of a chromel-alumel thermocouple calibrated up to 300° C. against a mercury thermometer. Pressures could not be measured directly. They were estimated from the graph shown in Fig. 1. Pressures are the ordinates and are expressed in bars and miles of rock in the earth's crust. Temperatures are the abscissae and are expressed in degrees C. as well as in miles of rock according to Holmes's geothermal gradient (4). On these coordinates are plotted the values of the specific volume of water as listed in the "International Critical Tables" and in the "Handbook of Physical Constants." Points of equal specific volumes have been joined by smooth curves which have been extrapolated into the areas of the graph for which there are no experimental data. From the graph, if the temperature and specific volume of water be

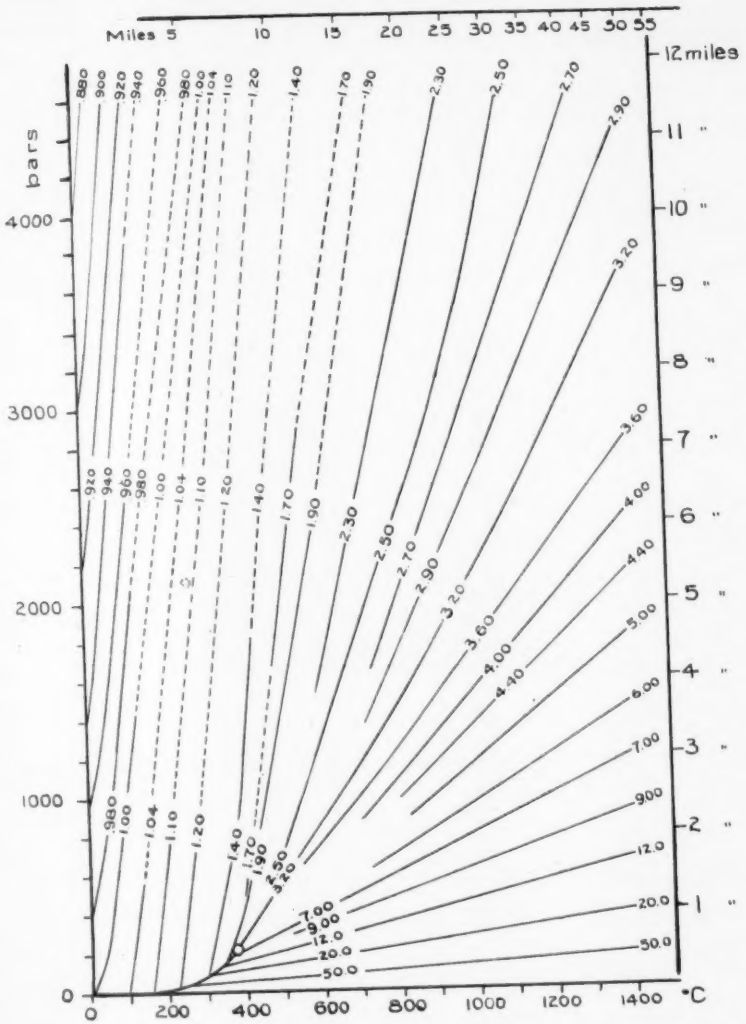

FIG. 1. Variation of the specific volume of water with temperature and pressure.

known, its pressure can be read directly. For example, if the bomb were 60 percent full initially, the maximum specific volume of the fluid in it (neglecting any expansion of the bomb itself) would be 1.67. If the bomb charge

were heated to 370° C., the pressure developed would be 250 atmospheres. Values thus obtained are however gross approximations. Bomb charges were not pure water; they contained large proportions of non-volatile salts and also, at high temperatures, unknown concentrations of H_2S.

Smithite ($Ag_2S.As_2S_3$).—Bomb charges for the synthesis of smithite are summarized in Table 1. The polysulphide solutions were made very concentrated, between 1 and 1.5 molal with respect to Na_2S. A proportion of 30–37 percent sulphur was added to facilitate the dissolution of silver and arsenic. The capacity of the bomb for the smithite experiments was only 24.4 cubic centimeters.

TABLE 1.
SMITHITE.*

	Experiment No.							
	4		5		6		7	
	gms.	%	gms.	%	gms.	%	gms.	%
Ag	0.30	1.0	0.20	0.8	0.31	1.2	0.30	1.2
As	5.00	17.5	1.60	6.4	2.40	9.1	2.40	9.1
$Na_2S.9H_2O$	9.45		5.26		7.95		7.95	
Na_2S		10.7		6.8		9.8		9.8
S	8.28	29.1	7.89	31.6	9.75	36.9	9.75	36.9
H_2O	5.50	41.7	10.00	54.4	6.00	43.0	6.00	43.0
Polysulphide	Na_2S_5		Na_2S_{10}		Na_2S_{10}		Na_2S_{10}	
Ag/As ratio	3/50		1/8		1/8		1/8	
Max. temp.	390° C.		385° C.		370° C.		390° C.	
Max. press.	885 bars		880 bars		760 bars		890 bars	
Time of heating	3 hours		3½ hours		3 hours		3 hours	
Time of cooling	13 hours		14 hours		15⅛ hours		14 hours	
Remarks					kept at 230°–250° C. 4½ hours		kept above 360° C. 2 hours	
Products	Smithite, colloform orpiment, caked sulphur		Smithite, colloform orpiment, caked sulphur, black crystals of tennantite		Smithite, proustite, orpiment, caked sulphur		Smithite, proustite, orpiment, caked sulphur, tennantite	

* The hydrosynthesis of smithite has been described elsewhere (1).

Much H_2S and some liquid escaped on opening the bomb. Red crystals, colloform orpiment, sulphur and colorless soluble salts coated the graphite lining of the bomb up to ¾ of its height. The red crystals (Fig. 3) identified as artificial smithite appeared as clusters of pellucid orange brown flakes delicately intergrown as a result of penetration twinning. When first taken out of the bomb the crystals were covered with botryoidal growths of orpiment and sulphur, but after washing with dilute ammonia and carbon disulphide, crystal faces and facettes appeared bright. A complete description of these artificial crystals of smithite has been published elsewhere by Professor M. A. Peacock (17).

Many of the smithite crystals contained liquid-gas inclusions. In the centre of Fig. 2, which is a photomicrograph of an artificial smithite crystal in transmitted light, may be seen irregular liquid inclusions each with a small gas bubble. If the temperature of formation of such crystals could be accurately determined they would provide a good test for the liquid-gas inclusion method of estimating the temperatures of vein formation (15).

Attempts to crystallize trechmannite, which might be a dimorph of smithite, failed. In experiments 5, 6 and 7 the sulphur content of the charge was made large to insure rapid dissolution of silver and arsenic. The cooling of charge 6 was arrested for 4½ hours at 230–250° C. in order to promote a possible inversion of smithite to trechmannite. Charge 7 was kept 2 hours at 360–370° C. in view of the possibility that trechmannite be the high temperature

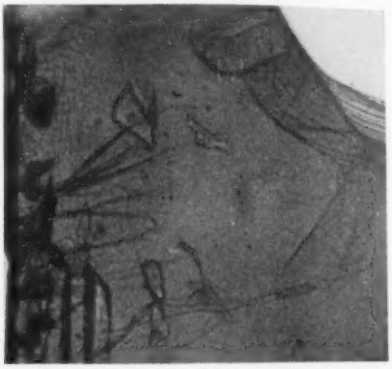

FIG. 2. Liquid-gas inclusions in artificial smithite. Transmitted light. × 200.

form. But no crystals of trechmannite were recognized in any of these experiments, and the smithite crystals showed no signs of inversion to or from any allomorph.

Proustite and Xanthoconite ($3Ag_2S.As_2S_3$).—Bomb charges for the synthesis of proustite and xanthoconite are given in Table 2. To those should be added charges 13 and 14 (Table 5) in which more than ⅔ of the silver was transformed into proustite and xanthoconite.

Charges 2 and 3 were similar to the ones used for smithite except for a greater silver to arsenic ratio. Charge 8 was an attempt, unsuccessful, to make pearceite. Potassium sulphide was used instead of sodium sulphide because the double salt $4Ag_2S.K_2S.2H_2O$ is more soluble than the sodium salt (6). A thinner graphite lining increased the capacity of the bomb to 72 cc and the water content of the solution was increased by 20 percent.

In all experiments, some H_2S was evolved on opening the bomb. When the brownish residual solutions were poured off, soluble sulpharsenites and ruby silver crystals were the only solids left. In 2 and 3, very small amounts

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of orpiment were detected. Proustite, always 10 to 20 times more abundant than xanthoconite, formed clusters attached to the lining of the bomb. Xanthoconite occurred in single unattached crystals which were concentrated in the upper part of the solids left in the bomb, as if they had fallen late from the solution. That, unfortunately, was the only indication obtained on the sequence of crystallization of proustite and xanthoconite. The two kinds of crystals were always equally bright and showed no sign of inversion from one to the other. The metastability of one of the two forms of $3Ag_2S.As_2S_3$ must be such that both can coexist in the same solution.

Miers (14) examined several natural occurrences of the two minerals and concluded that proustite and xanthoconite were always contemporaneous.

TABLE 2.

PROUSTITE—XANTHOCONITE.

	2		3		8	
	gms.	%	gms.	%	gms.	%
Ag	1.00	3.4	1.15	3.8	3.33	4.7
As	3.00	10.2	3.24	10.7	3.33	4.7
$Na_2S.9H_2O$	15.00		16.20			
Na_2S		16.8		17.5		
K_2S					11.17	15.8
S	6.08	20.8	6.55	21.7	11.21	15.8
H_2O	4.10	48.8	3.10	46.3	41.7	59.0
Polysulphide	Na_2S_3		Na_2S_3		K_2S_3	
Ag/As	1/3		0.355		1	
Max. temp.	335° C.		375° C.		400° C.	
Max. press.	420 bars		780 bars		1,180 bars	
Time heating	2½ hours		2½ hours		2 hours	
Time cooling	12 hours		13½ hours		14 hours	
Remarks					kept above 380° C. 1¼ hours	
Products	Proustite, xanthoconite, small amount of orpiment		Proustite, xanthoconite, very small amount of orpiment		Proustite, xanthoconite, (nothing else)	

However, at Sainte-Marie aux Mines (Markirch), Alsace, Miers noticed: "crystals (of xanthoconite) in the recesses of a fine specimen of proustite. . . ." Parsons (16), describing xanthoconite from Cobalt, Ontario, mentioned: "Proustite in well formed crystals protruding from the hemispherical drusy aggregates of the xanthoconite." He also quoted Breithaupt as having described similar relations in specimens from Freiberg, Germany. In the General Petite Mine, Idaho, according to Shannon (22), "The xanthoconite forms hemispherical masses up to 2 millimeters in diameter deposited around and apparently later than the proustite." Possibly the normal sequence is proustite first, followed by xanthoconite as indicated in my experiments and observed by Shannon. Most alkaline solutions of Ag, As and S, either in nature or in vitro, would dump all their excess $3Ag_2S.As_2S_3$ as proustite at temperatures higher than the maximum allowable for the formation of xanthoconite. Only solutions exceptionally rich in virtual $3Ag_2S.As_2S_3$ would be able to

carry the precipitation of $3Ag_2S.As_2S_3$ into the low-temperature range of xanthoconite. This hypothesis would explain (a) the extreme scarcity of xanthoconite in nature, (b) the fact that xanthoconite has not been mentioned in previous hydrosyntheses of proustite, in particular that of de Sénarmont (21). In the type of occurrence described by Parsons the crystals of proustite would be due to a resurgence of hot solution, to a "second period

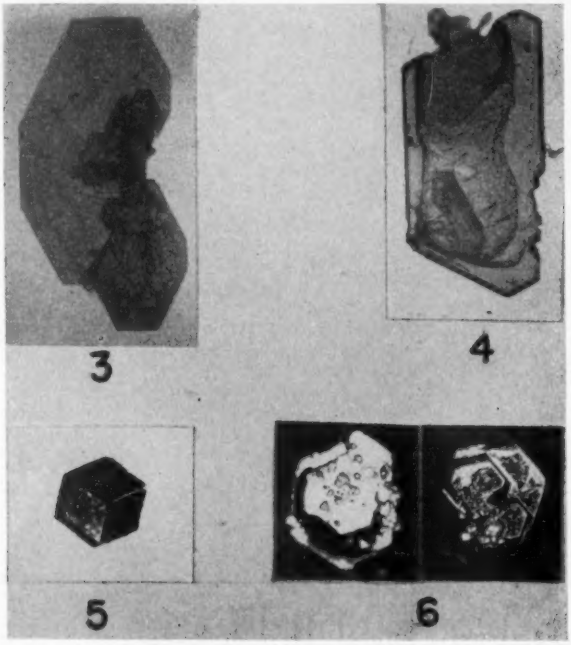


FIG. 3. Artificial smithite $Ag_2S.As_2S_3$. × 38.
FIG. 4. Artificial proustite $3Ag_2S.As_2S_3$. × 40.
FIG. 5. Artificial xanthoconite $3Ag_2S.As_2S_3$. × 38.
FIG. 6. Cubo-octahedral crystals $9Ag_2S.As_2S_3$?. × 38.

of mineralization." It is proposed to investigate this question experimentally when the necessary equipment has been assembled.

The bomb charges yielded proustite crystals of varying habit, commonly low rhombohedra (Fig. 5) with a narrow prism, unlike natural crystals which are usually scalenohedral. The xanthoconite crystals are bright amber-colored laths (Fig. 4) more flattened than natural crystals but otherwise resembling natural xanthoconite in shape, color and even minor imperfections. These crystals of artificial proustite and xanthoconite are described in a note by Professor Peacock (18).

Argentite, Ag_2S, and Wire Silver.—In Table 3 are summarized three experiments which failed for technical reasons but gave interesting results. The bomb charge of experiment 1 should have yielded proustite and xanthoconite. When the bomb was opened, it was completely dry and contained argentite crystals and soluble sodium salts. There was no sign of leakage; the solution must have been entirely absorbed by a graphite lining, half an inch thick, which protected the interior of the pressure vessel. Crucible graphite has a porosity of 20 percent, and the volume of lining was such that the latter could accommodate all the solution.[2] In the heating stage, the solution penetrated the lining before much of the silver had dissolved, and argentite crystals were left behind. Most of them were rounded cubo-octahedra, 0.2 to 0.5 mm in diameter, supported on stalks of wire silver.

TABLE 3.
ARGENTITE, WIRE SILVER.

	1		9		10	
	gms.	%	gms.	%	gms.	%
Ag	1.00	2.9	2.00	2.8	1.00	1.7
As	2.00	5.8	0.50	0.7	0.25	0.4
$Na_2S.9H_2O$	20.00					
Na_2S		19.0				
K_2S			11.18	16.5	5.52	9.7
S	4.14	12.1	12.60	18.5	6.30	11.0
H_2O	7.20	60.2	41.70	61.5	43.80	77.1
Polysulphide	Na_2S_2		K_2S_3		K_2S_3	
Ag/As	1/2		4/1		4/1	
Max. temp.	370° C.		350° C.		circa 500° C.	
Max. press.	850 bars		20–30 bars		circa 3,000	
Time heating	2½ hours		2½ hours		3 hours	
Time cooling	12½ hours		12 hours		14 hours	
Remarks	Solution saturated graphite lining		Began to leak at 225° C.		Thermocouple faulty. Bomb exploded	
Products	Argentite in rounded octahedra and skeletal arborescent groups		Tennantite, wire silver, argentite		Tiny argentite crystals (octahedral), wire silver	

Experiments 9 and 10 were attempts at synthesizing pearceite. Mechanical failure of the pressure bomb modified the reactions considerably. In experiment 9, the bomb had not been closed tightly enough. During heating, the solution seeped along a copper gasket under the lid of the pressure vessel and cut a channel through it. The first signs of leakage were noted at 225° C. At 300°–350° C. the hissing of escaping H_2S-water vapor became continuous, and heating was stopped. There was no liquid in the bomb when opened. On the graphite lining was a fine reddish dust of proustite and smithite. Most of the silver had been converted into argentite crystals adorned with curly whiskers of wire silver. Some spongy "moss silver" was also found. Near

[2] When the lining was later broken and taken out of the bomb, little smithite crystals were seen in the graphite. Some had grown between the steel wall and the graphite lining.

the copper gasket, and around the interior rim of the bomb, was a continuous fringe of curly wire silver, slightly tarnished.

In experiment 10, the temperature-measuring apparatus failed. At a temperature read as 220° C., the bomb exploded. The interior of the furnace was then cherry red, and the bomb must have been very close to red heat, at least 500° C. The copper gasket stretched under a pressure probably close to 3,000 bars and the solution escaped violently. Argentite and wire silver with a minor amount of proustite and soluble salts were left in the bomb.

These experiments indicated that, normally, the silver and arsenic were entirely dissolved during the heating of the charges and that ruby silvers precipitated during the cooling stages. When the bomb failed, rapid removal of sulphur as H_2S or oxy-ions caused the precipitation of silver as argentite and wire silver at high temperature according to the reversible reaction (3):

$$2Ag + S \underset{\text{high temp.}}{\overset{\text{low temp.}}{\rightleftharpoons}} Ag_2S.$$

In experiment 1, wire silver sprouted crystals of argentite on cooling. In experiments 9 and 10 the solutions and gases escaped; no reconversion of wire silver to argentite was possible except for a slight iridescent tarnish. In experiment 9 another chemical reaction caused the formation of a fringe of wire silver around the rim of the bomb. During the relatively slow leakage of the solution past the copper gasket, metallic copper was dissolved and displaced silver from the solution.

Thus in nature, hypogene metallic silver might indicate conditions of low pressure and rapid removal of sulphur from the ore bearing fluid.

Compounds with High Ag-As Ratios.—In experiments 11 and 12, summarized in Table 4, the ratio of silver to arsenic (by weight) was made 7/1 and 5/1 respectively. After heating and cooling, the residual solutions had the same aspect as in the previous experiments. The solids consisted of soluble salts, and metallic crystals which do not correspond to any known mineral. Most of these crystals were equant and blocky, with a prominent octahedral form. Some were platy and had a hexagonal outline (Fig. 6). Two of the platy crystals were measured on a two-circle goniometer. The interfacial angles were those between the cube, octahedron and rhombic dodecahedron. An X-ray power photograph gave a typical isometric pattern. The film was indexed by Professor M. A. Peacock and the cube edge found to be $a = 12.45$ kX.

The crystals, dissolved in boiling nitric acid, were found by microchemical tests (23) to contain Ag, As and S. Assuming the crystals to be a compound of Ag_2S and As_2S_3, some idea of their composition was sought by means of the relation:

$$\text{Spec. gr.} = \frac{n\ (\text{molecular wt.})\ 1.65}{a^3}$$

where: 1.65 = reciprocal of Avogadro's number $\times 10^{24}$,
n (molecular wt.) = cell content of the crystal,
a = cube edge (in this case 12.45).

Direct measurement of the specific gravity of the tiny crystals being impossible, several molecular weights were assumed, and the corresponding specific gravities were calculated and plotted on the graph shown in Fig. 7. The nature of the bomb charges excluded any composition lower in Ag_2S than proustite. Molecular combinations for which the calculated specific gravity did not lie on or close to the curve of Fig. 7 were also ruled out. Only two cell contents, $3(9Ag_2S.As_2S_3)$ and $3(7Ag_2S.2As_2S_3)$, fulfilled the necessary conditions. Of these, the first is more likely in a cubic space group, and $9Ag_2S.As_2S_3$ is also the composition ascribed to isometric crystals obtained from melts high in Ag_2S by Gaudin and McGlashan (7). However, attempts to reproduce the compound, by fusing weighed charges of Ag, As and S in

TABLE 4.
$9Ag_2S \cdot As_2S_3$?

	11		12		15	
	gms.	%	gms.	%	gms.	%
Ag	0.70	1.4	1.00	2.0	Ag 2.00	2.8
					Cu 0.53	0.8
As	0.10	0.2	0.20	0.4	0.50	0.7
K_2S	4.90	10.1	7.06	14.2	18.00	25.4
S	5.60	11.5	4.36	8.8	21.70	30.6
H_2O	36.00	76.8	37.20	74.6	28.16	39.7
Polysulphide	K_2S_6		K_2S_3		K_2S_6	
Ag/As	7/1		5/1		Ag+Cu/As 5/1	
Max. temp.	410° C.		420° C.		416° C.	
Max. press.	740 bars		900 bars		1,200 bars	
Time heating	2½ hours		2½ hours		2 hours	
Time cooling	15 hours		15 hours		15 hours	
Products	Metallic cubo-octahedral crystals		Metallic cubo-octahedral crystals		Tennantite, metallic cubo-octahedral crystals	

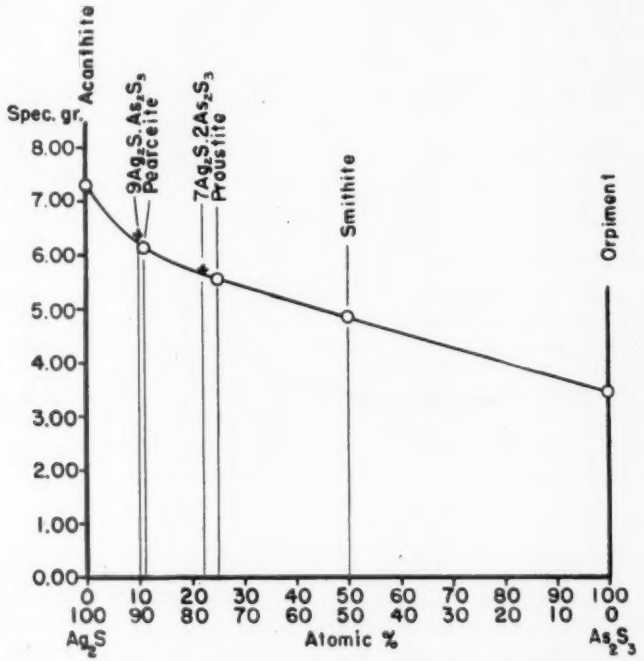
evacuated pyrex tubes, did not succeed and the composition of the little isometric crystals remains to be established.

In experiments 13 and 14 (Table 5), the ratios of silver to arsenic were made 2.88 to 1 and 4 to 1 respectively. Most of the silver combined as proustite and xanthoconite. But small hexagonal plates resembling pearceite were also found. In experiment 13, some of those crystals were shaped like concertinas, as if several hexagonal plates had been superimposed. The angles measured from the large base of the hexagonal plates to the side faces did not agree with the angles listed for pearceite in Dana (5). The artificial hexagonal crystals possess the forms c(0001), q(1012) and p(1011). The angle cp is 70° 10′ (6 measurements) and the angle cq is 53° 46′. The axial ratio is $a:c = 1:2.401$. Mr. S. A. Forman took a rotation X-ray photograph of one "concertina" crystal rotated about an axis normal to its base. He confirmed the hexagonal symmetry with a long period along the axis of rotation [0001]. The composition of these crystals could not be determined.

So far, attempts to reproduce pearceite have failed, but it is proposed to

undertake further syntheses of the high-silver compounds in the Ag-As-S system. Possibly, a small amount of copper (minimum 3 percent) always present in natural pearceite should be included in its formula as: $7Ag_2S.CuS.As_2S_3$. Experiment 15, however, in which Cu was added, did not yield pearceite.

Residual Solutions.—The residual solutions in all experiments smelled strongly of H_2S and were alkaline to litmus. Qualitative chemical tests were



Specific gravities against compositions in the system $Ag_2S - As_2S_3$

FIG. 7.

made on the solutions (including all the soluble salts left in the bomb) from experiments 3 and 4. At first these solutions were brownish, but they slowly turned dark green due to the formation of colloidal ferrous sulphide (12) which finally flocculated and settled as a black precipitate. After a first filtration, to remove bits of graphite, precipitated FeS, crystals of orpiment and ruby silvers, the solutions were made acid to litmus with HCl. A copious yellow precipitate of arsenic sulphide formed instantly. The supernatant

TABLE 5.
HEXAGONAL CRYSTALS.

	13		14	
	gms.	%	gms.	%
Ag	1.00	2.0	2.00	3.6
As	0.35	0.7	0.50	0.9
K_2S	8.25	16.1	16.50	28.0
S	5.20	10.2	10.25	17.4
H_2O	36.2	71.0	29.70	50.1
Polysulphide	K_2S_3		K_2S_3	
Ag/As	2.88/1		4/1	
Max. temp.	420° C.		403° C.	
Max. press.	900 bars		650 bars	
Time heating	3 hours		1½ hours	
Time cooling	15 hours		14 hours	
Products	Proustite, xanthoconite, "concertina" hexagonal crystal, cubo-octahedral crystals		Proustite, xanthoconite, hexagonal plates, cubo-octahedral crystals	

liquid, when free of arsenic, gave a fine white precipitate of barium sulphate on addition of barium chloride. The yellow precipitate dissolved in ammonia leaving a small yellowish residue soluble in carbon disulphide and identified as sulphur. This sulphur probably resulted from the breakdown of polysulphides on acidification of the solutions. The tests indicate the following anions: $S_x^{=}$, $As_2S_3^{=}$ (and possibly $AsO_3^{=}$) and $SO_4^{=}$. Such a solution, because of its alkalinity, could be in equilibrium with carbonates and, at the same time, precipitate calcium or other insoluble sulphates.

SUMMARY AND CONCLUSIONS.

In concentrated solutions of sodium (or potassium) polysulphides containing silver and arsenic, the arsenical ruby silvers can easily be prepared, in good crystals, at temperatures below 400° C. and pressures lower than 1,000 atmospheres. When the atomic ratio of silver to arsenic in the solution is less than 0.10 smithite crystallizes with orpiment. There is no compound Ag_2S-As_2S_3 lower in Ag than smithite. When the Ag-As ratio is between 0.10 and 2.5 proustite and xanthoconite are formed, proustite apparently preceding xanthoconite. With Ag-As ratios (atomic) greater than 2.5, isometric and hexagonal crystals of unknown compositions have been obtained, the crystallographic measurements of which do not correspond to those of any known minerals. Pearceite ($8Ag_2S.As_2S_3$) has not yet been synthesized by wet methods.

If, during the course of an experiment, the pressure is rapidly released and some of the fluid allowed to escape, argentite and wire silver are formed, although the solution may contain much sulphur and arsenic. Such conditions could easily obtain in epithermal veins.

The solutions in these experiments are alkaline and contain $SO_4^{=}$ ions. They would therefore favor the formation of quartz (10), calcite, dolomite,

barite and anhydrite, all of which are found in the gangues of silver veins. The theory of deposition of primary silver sulphosalts, argentite and native silver from alkali sulphide solutions is thus strongly supported by experimental work.

The crystallization of ruby silvers from such solutions necessitates concentrations of As_2S_3 far greater than the stoichiometric requirements of the compounds. In the case of smithite this concentration of As_2S_3 is so great as to be beyond the scope of natural ore bearing fluids. The mineral therefore is very rare. Proustite is the common arsenical ruby silver; it not only requires less As_2S_3 than smithite but allows considerable variation in the concentration of arsenic sulphide in the solution. Furthermore, as suggested above, the metastability of proustite prevents its inversion to its dimorph xanthoconite. The latter, a rare mineral, can crystallize only from solutions very rich in virtual $3Ag_2S.As_2S_3$. Some new data on the crystallography of the arsenical ruby silvers have been obtained from the artificially grown crystals (18). Synthesis in alkali sulphide solutions promises to be a valuable method of obtaining good crystals, free of impurities and contamination, for mineralogical studies on the sulphosalts.

ACKNOWLEDGMENT.

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UNIVERSITÉ LAVAL,
QUÉBEC, CANADA,
Dec. 16, 1947.

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ORIGIN AND ALTERATION OF CHROMITES FROM EGYPT.

MAHMOUD SAYED AMIN.

ABSTRACT.

The main chromite deposits of Barramia and Umm Salatit are lenticular and are generally aligned within a definite trend. They were segregated at an early stage in deep horizons, then carried up as solid inclusions by the ultramafic silicate magma during its emplacement. The ore segregated from peridotite poor in feldspar and low in iron and aluminium. The chromite was corroded by the silicate fluids, and also altered by the late magmatic fluids that serpentinized and steatitized the ultramafic country rock. The deposits also include some late magmatic disseminated ore and hydrothermal chromite veinlets.

INTRODUCTION.

The writer, when employed by the Misr Co. for mines and quarries, had an opportunity to study the chromite deposits and their associated rocks in the region of Barramia and Umm Salatit. The area examined occurs 100 kilometers east of Idfu on the Nile (Fig. 1).

The chromite bodies are contained in serpentine or in talc carbonate formed from ancient peridotite originally composed of olivine and enstatite. The serpentine and talc carbonate were intruded into metasomatized and metamorphosed rocks of older age and were also intruded by granites of younger age. These formations are shown in the geological map prepared by the Geological Survey of Egypt (Fig. 2). The position and strike of the chromite deposits were put on the original map by the writer. The chromite deposits consist mainly of lenticular bodies, which in few places are associated with chromite veinlets and disseminated ore. The long axes of the lenticular bodies are more or less aligned east-west or northeast-southwest. This direction seems to be an important tectonic line in the area, since the elongated serpentine masses and schistose rocks strike in the same direction. Also the quartz gold veins that traverse the schists have more or less the same strike (Fig. 2).

The writer has examined twelve occurrences, which are shown in Fig. 2, but only three were examined in detail. This paper deals with the origin and alteration of the different deposits. The lenticular bodies are assumed to have been segregated at an early stage in deep horizons from a feldspar-poor peridotite low in aluminium or iron. The crystallized bodies were carried by the ultramafic magma as solid inclusions. The chromite was corroded by the magmatic silicate fluids and altered by the late hydrothermal fluids that altered the ultramafics to serpentines and talc carbonates. The disseminated ore deposits are proved to be of late magmatic origin whereas the chromite veinlets are assumed to be of hydrothermal origin.

FIELD RELATIONS.

The chromite deposits are found in the serpentine or in the associated talc carbonate, and in a few places in the metamorphosed rocks. The deposits are either in the form of lenticular bodies, veinlets or disseminated ore. The lenticular bodies are equivalent to the sack-form deposits described by Sampson (1).[1] They are either elongated lenticular bodies with long intermediate and

FIG. 1. Key map of Egypt showing the position of the area examined in the Eastern desert of Egypt. The deposits lie between Idfu on the Nile and the Red Sea, at the position of "R" in the word "Desert."

short axes or flattened lenticular bodies with two equal axes and a shorter third one. The field relation of these bodies indicates that they have a definite trend. The long axes of the elongated bodies strike east-west or less commonly northeast-southwest. Some of the lenticular bodies are not elongated in one direction but are flattened along a plane, and these planes also strike in the same direction. The lenticular bodies differ in size, ranging from a few

[1] Numbers in parentheses refer to Bibliography at end of paper.

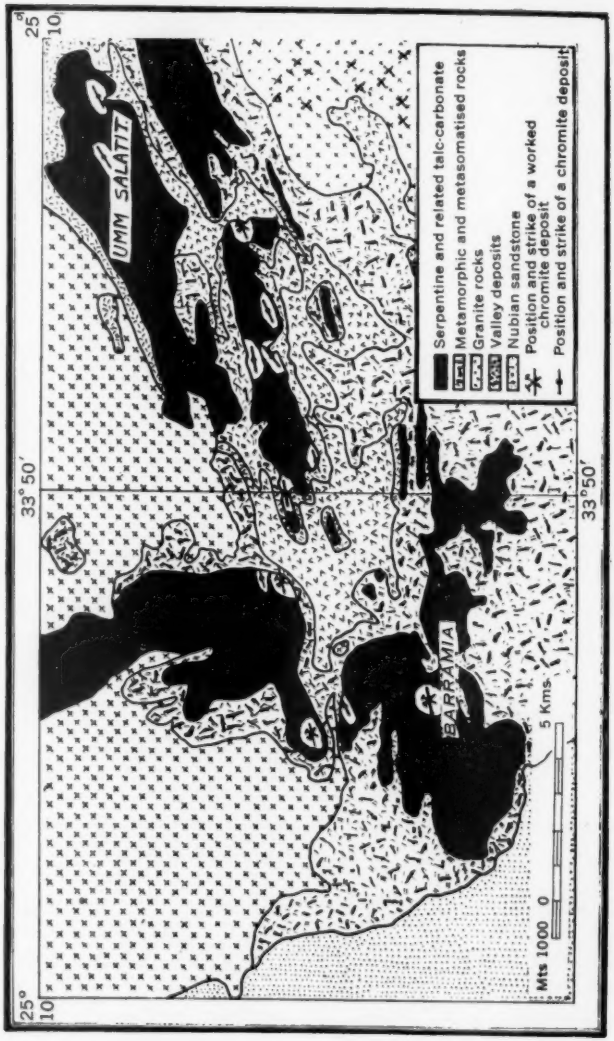


FIG. 2. Geological map of Barramia and Umm Salatit.

centimeters to several meters in length or width. They are the deposits that were exploited during World War II. The other deposits, namely, the veinlets or the disseminated ore are subsidiary.

The veinlets occur near the chromite lenses. They measure only from 2 to 3 centimeters in thickness and have a maximum extension of 5 to 6 meters. The serpentine traversed by the veinlets has a bright yellowish green color.

The disseminated ore occurs in the serpentine of Barramia and in the talc carbonate of Umm Salatit.

DESCRIPTION OF DEPOSITS.

The geological map (Fig. 2) shows the distribution of the different chromite deposits of which the writer has examined three deposits in detail.

Deposit No. 1.—This deposit is situated 1 Km east of the Barramia well. It consists of one lens of chromite (Fig. 3), which is 14 meters long, 9 meters

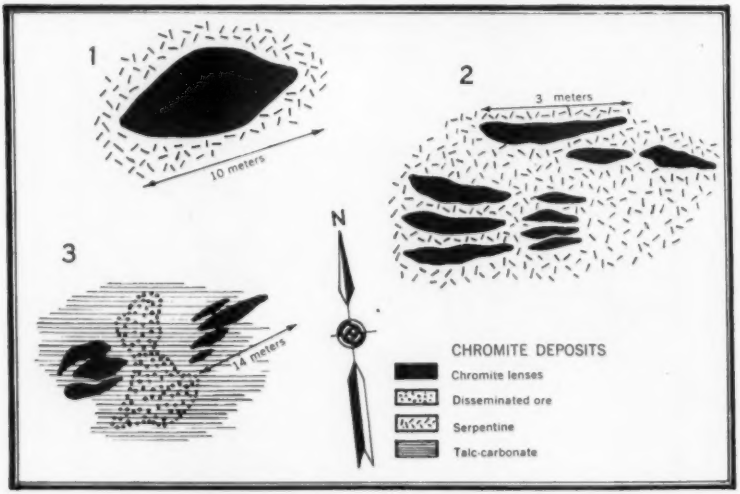
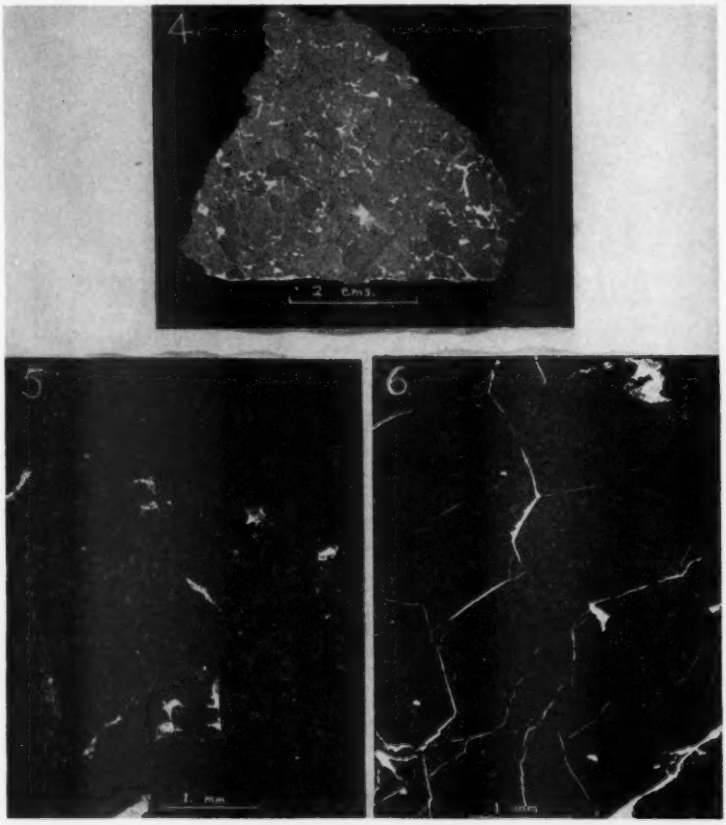


FIG. 3. Diagrams of the three deposits examined in detail.

wide and 7 meters thick and strikes northeast and dips 70 degrees southeast. The chromite lens is completely surrounded by a sheath of schistose green serpentine which is from 20 to 25 centimeters in thickness. The lens consists of massive black ore composed of chromite and other gangue minerals such as chlorite and magnesite, and is therefore chromitite. The chromitite is not uniform in texture; the center consists of coarse chromite with few gangue minerals (Fig. 4) and the margins of the body are formed of fine chromite with abundant gangue minerals (Fig. 13). The fine chromitite is also found along fractures or joints that cut the lens.



Coarse chromitite.

FIG. 4. Specimen of coarse chromitite with few silicates.
FIG. 5. Thin section of a coarse chromitite with few narrow angular interspaces full of chlorite. The boundaries of the chromite crystals are not defined.
FIG. 6. Thin section of a coarse chromitite with few narrow interspaces and thin films of chlorite demarcating the chromite crystals.

Microscopically, the chromitite of the center, away from the joints, consists of interlocked crystals of chromite measuring from 3 to 7 mm in length. The crystals are subhedral but more or less angular and with or without fractures. They enclose angular narrow interspaces filled with chlorite (Fig. 5). The same specimen may contain wide rounded interspaces surrounded by subangular chromite crystals. The translucent parts of the chromite are cherry red.

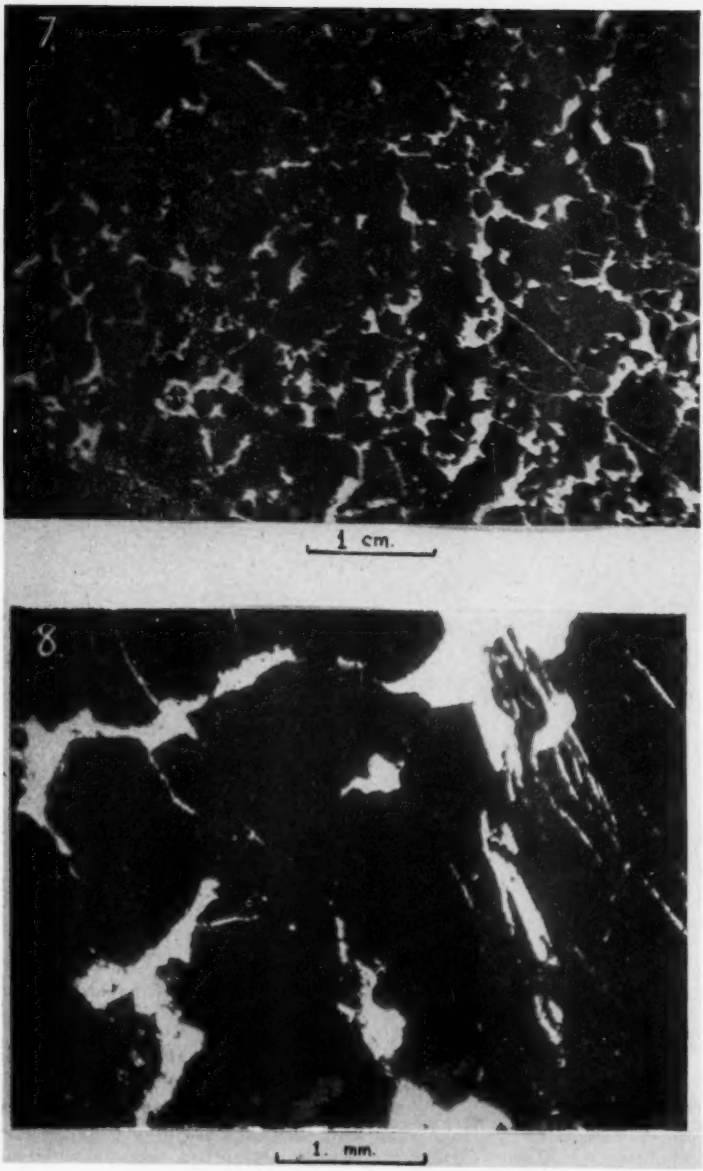
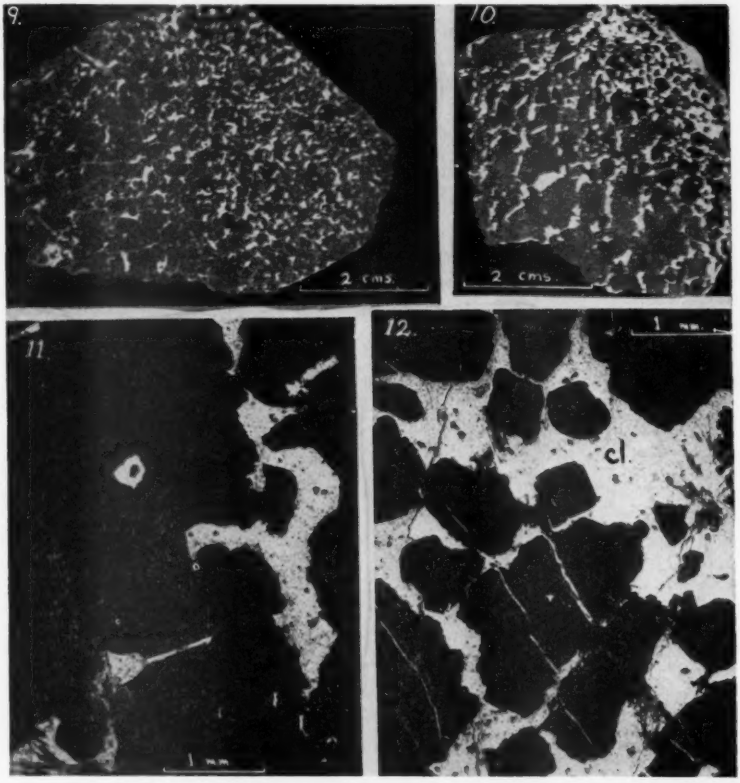


FIG. 7. Specimen of coarse chromitite with abundant silicates on one side only.
FIG. 8. Thin section of coarse chromitite of Fig. 7 showing the wide interspaces between the coarse chromite crystals.



Coarse and fine chromitite.

FIGS. 9 AND 10. Specimens of coarse chromitite gradually changing to fine chromitite.

FIG. 11. Thin section of the coarse chromitite part of Fig. 10 showing the embayment of the chromite crystals by the chlorite that fills the wide interspaces.

FIG. 12. Thin section of the fine chromitite part of Fig. 10 showing the rounded and fractured chromite crystals, which are corroded by the chlorite filling the wide interspaces. The chlorite (cl) contains some magnesite (mg).

Near the principal joints of the ore body, the coarse crystals have lost their angularity and are rounded, embayed, and separated by irregular wide interspaces (Fig. 8). The widened interspaces may enclose corroded rounded chromite crystals.

The chromitite from the margins of the lens or in direct contact with the joints consist of fine chromite crystals measuring from 2 to 4 mm in diameter.

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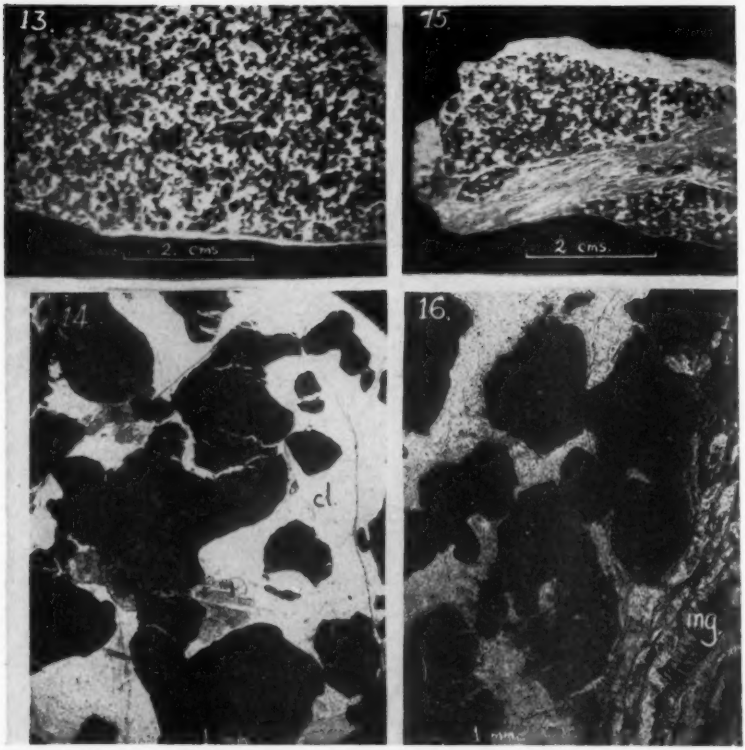

Fine chromitite.

FIG. 13. Specimen of fine chromitite with abundant silicates.

FIG. 14. Thin section of the fine chromitite in Fig. 13 showing the fine rounded and embayed chromite crystals, separated by wide spaces full of chlorite (cl) and magnesite (mg).

FIG. 15. Specimen of fine chromitite traversed with magnesite veinlets.

FIG. 16. Thin section of the fine chromitite in Fig. 15 formed of rounded chromite crystals with chlorite in the interspaces. The chromite and the chlorite are traversed by magnesite (mg).

They are rounded and embayed by chlorite, which fills the spaces between the grains (Figs. 12, 14). These are no longer called interspaces since they surround the chromite grains completely. The chromite shows evidences of disruption and the disrupted fragments are also rounded and corroded by chlorite. The chlorite is generally associated with magnesite (Fig. 14). In places, the fine chromitite is traversed by thin veinlets of magnesite (Figs. 15, 16).

The surface of the lens as well as the surfaces of the joints are covered by a scaly brownish black veneer up to one centimeter in thickness. This consists of a black opaque mineral strongly fractured and divided into minute angular pieces. The fractures contain chlorite. The change of chromite to the opaque mineral may be observed microscopically. The cherry red chromite from the margin of the lens is traversed by a network of black lines and these increase gradually towards the surface of the ore body (Fig. 21) until the crystal is completely replaced. Relics of the cherry red chromite are in places preserved in the opaque black mineral.

The formation of black lines in chromite was described by Phillips in the chromites of Shetland (3) and also by Lewis in the Carolina chromites (11). Lewis suggested that leaching of alumina and magnesia from the chromite borders or along fractures causes relative enrichment in ferric oxide and hence the chromite becomes opaque and black. The black lines or black veneer, mentioned above, has apparently been formed in a similar manner. Alteration releases alumina and magnesia; the former changes the serpentine in the interspaces to chlorite and the latter forms magnesite that appears in the marginal zone either as grains in the interspaces (Fig. 14) or as veinlets cutting the ore (Fig. 15).

The green serpentine sheath surrounding the chromite lens consists of coarse antigorite lamella, a little chromite and some magnesite veinlets. This sheath separates the serpentine country from the chromite lens. The serpentine country rock is formed of bastite pseudomorphs and serpentine meshes, or of antigorite lamella with some meshes. This indicates that the country rock was olivine-pyroxene peridotite.

Deposit No. 2.—This is situated seven kilometers east of the Barramia well. The deposit consists of ten small lenses ranging in length from two to three meters. The long axes of the lenses strike east-west and dip 10 degrees to north. The lenses may be connected by chromite veinlets measuring from 2 to 3 centimeters in thickness. The deposit is contained in a brownish green serpentine which near the lenses becomes stained with red iron oxide. The serpentine bordering the veinlets has a characteristic bright yellowish-green color. The serpentine country rock northeast of the lenses contains scattered chromite grains forming a disseminated chromite deposit.

The lenses have a chromitite center consisting of angular, subhedral, or euhedral chromite crystals separated by thin films of chlorite and enclosing a few angular interspaces filled by chlorite (Fig. 6). In places, the chromite is rounded or subangular and thus encloses rounded interspaces. Generally the chromite has medium texture measuring from 1.5 to 2 mm in diameter and contains few or no fractures. The marginal chromitite is finer and consists of corroded chromite crystals.

The chromite veinlets occur in serpentine which consists of fine antigorite lamellae, serpentine meshes, and limonite. The antigorite lamellae are in places embedded in the limonite matrix in ophitic structure. The antigorite is replaced by limonite. The contact of the chromite veinlets with serpentine is more or less sharp and undulating (Fig. 26). The veinlets send apophyses into the rock (Fig. 27). The chromitite of the veinlet consists of angular in-

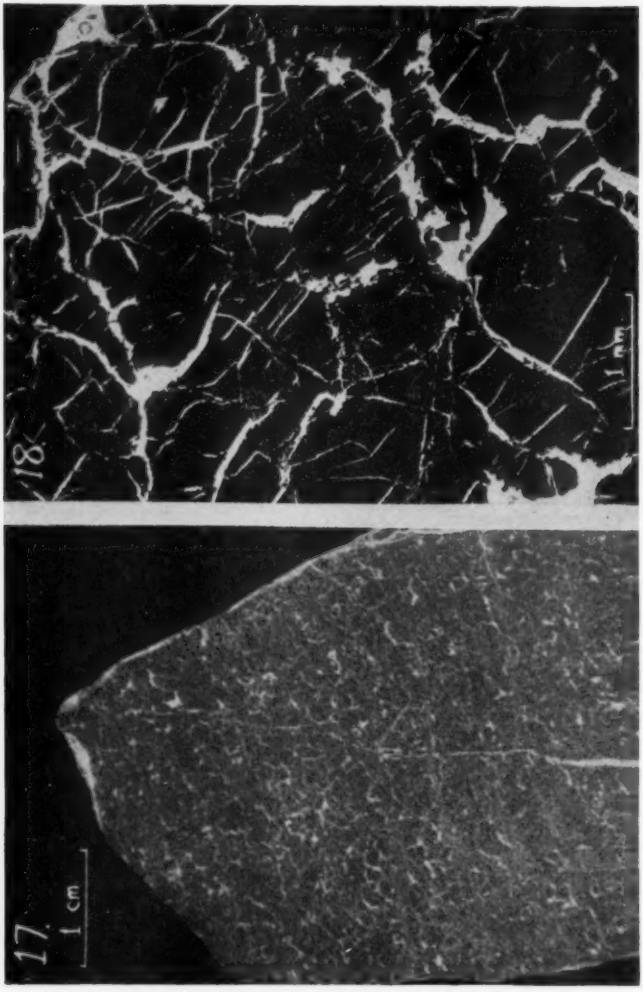

FIG. 17. Specimen of fine fractured chromitite from the deposit No. 3.
FIG. 18. Thin section of the fine chromitite in Fig. 17. The chromite is strongly fractured.

terlocked crystals of chromite measuring from 1.5 to 3 mm in diameter. They enclose angular interspaces filled by serpentine which has positive elongation and bluish gray interference colors. The interspaces in the chromitite of the lenses contain chlorite instead of the serpentine present in the interspaces of the veinlets.

The disseminated ore consists of yellow-green serpentine matrix with scattered grains of chromite measuring from 1 to 3 mm in diameter. The matrix is formed of antigorite lamellae with relics of serpentine meshes. The chromite is subangular or rounded and contains some fractures full of antigorite. In places the chromite encloses rounded or ovoidal relics of mesh serpentine

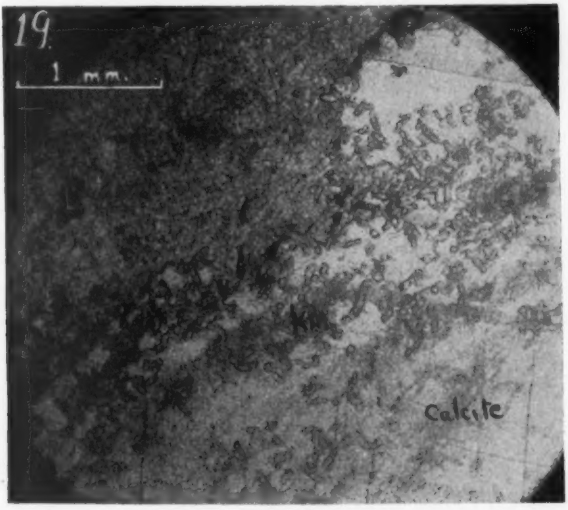

FIG. 19. Thin section of calcite from the talc carbonate sheath surrounding the chromite lenses of the deposit No. 3. It shows calcite and kaemmeririte (km).

whose appearance indicates an original poikilitic texture of olivine in chromite (Fig. 23). Both the chromite and the serpentine are traversed by carbonate veinlets.

The country rock of these deposits consists essentially of serpentine meshes with or without antigorite lamellae indicating that the original rock was dunite containing a small amount of pyroxene.

Deposit No. 3.—This deposit is situated 17 kilometers north of the Barramia well. It consists of seven lenticular bodies. Each is a flattened lens with a circular basal outline. They lie vertically with their basal planes striking N 30°–80° E and dipping 80 degrees southeast. The country rock of the lenses consists of talc carbonate formed after serpentine. The chromite lenses

are surrounded by a sheath of coarse talc carbonate. The lenticular chromite deposits are accompanied by disseminated deposits (Fig. 3).

The chromite lenses consist of chromitite made up of medium grained chromite crystals measuring from 2 to 4 mm in diameter. The chromite is opaque and black in color. It consists of subangular, subhedral, and strongly fractured crystals (Fig. 18). The fractures and the interspaces between the crystals are filled with chlorite, talc, and magnesite. The chlorite is fine and nearly isotropic. The interspaces are either angular or rounded. The talc carbonate sheath surrounding the lenses consists of coarse talc flakes and calcite rhombhedrons. The talc flakes are transparent, pale green, and shiny, and the calcite rhombhedrons are well formed crystals measuring from 2 to 3 centi-

TABLE I.

	Chromitites				Silicate rock		
	A	A′	B	C	a	c	b
SiO_2	4.39	3.12	8.64	4.68	35.64	41.44	31.02
Al_2O_3	24.17	11.84	6.72	29.40	1.00	1.81	2.78
FeO	2.55	3.46	1.53	1.32	2.15	1.47	2.50
Fe_2O_3	12.84	31.21	28.09	14.90	1.35	2.51	2.37
MnO					.055	.047	.071
TiO_2	nil	nil	nil	nil	nil	nil	nil
CaO				1.68	1.10	1.20	.40
MgO	18.90	10.86	12.06	9.82	40.46	40.10	35.50
Cr_2O_3	36.41	39.01	41.87	38.01	.270	.245	.294
Na_2O					nil	nil	nil
K_2O					nil	nil	nil
CO_2					7.60	.91	22.60
H_2O-					.46	.15	.08
H_2O+					9.73	10.25	2.53

A: Chromitite from the center of the large lens in Deposit No. 1.
A′: Chromitite from the border of the large lens in Deposit No. 1.
B: Chromitite from the Deposit No. 3.
C: Chromitite from the center of a small lens in Deposit No. 2.
a: Serpentine from Deposit No. 1.
b: Talc carbonate from Deposit No. 3.
c: Serpentine from Deposit No. 2.

meters in length. They are of creamy color, but in places they possess a violet color, particularly at the contact with chromite, due to the presence of tiny lamellae of kaemmeririte (Fig. 19). These have a violet color, weak pleochroism, negative elongation and straight extinction. The kaemmeririte is embedded in the calcite or in the talc of the sheath and in places it replaces the chromite crystals.

The disseminated ore consists of a matrix of talc flakes and magnesite grains containing fresh or decomposed chromite (Fig. 24). The decomposed chromite is replaced by magnesite full of magnetite dust. These are usually associated with chlorite lamellae whose formation is attributed to the alumina liberated during the alteration of chromite. The chlorite is pale green with ultra-blue interference colors.

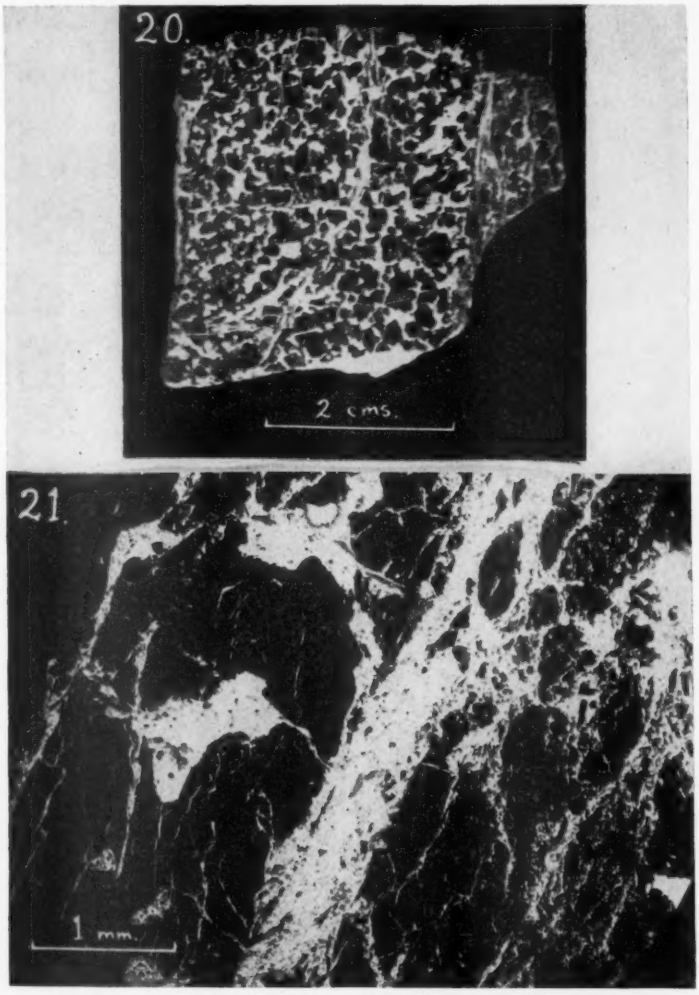

FIG. 20. Specimen of fine chromitite from the margin of the lens in deposit No. 1.

FIG. 21. Thin section of the fine chromitite in Fig. 20 showing the replacement of chromite (left) by fine opaque black mineral (right).

CHEMISTRY OF THE CHROMITE DEPOSITS.

The microscopic study of the chromite ore does not give sufficient data for the determination of their origin. On the other hand, the chemical analyses of the chromites do permit conclusions about its mode of formation. The following table gives the chemical analyses of the chromitites and their associated silicate rocks of serpentines and talc carbonate.

Stevens (4), Thayer (5) and Van der Walt (7) have made detailed studies of the chemical composition of chromites and their conclusions are helpful in this work. Thayer proposed a formula for chromite which is found useful in comparing the different chromites of Barramia. The analyses given in Table I are of chromitites (chromites and silicate gangue minerals); therefore before constructing the formulae proposed by Thayer, the constituents of the gangue minerals must be subtracted from the analyses of the chromitites. The gangue silicates consist of chlorite which is calculated as amesite $H_4(MgFe)_2Al_2SiO_9$, and talc $(OH)_2Mg_3Si_4O_{10}$. Table II shows the composition of the chromitites, the gangue silicates and the calculated chromites. The composition is given in molecular proportions.

TABLE II.

	A			A′			B			C		
	CRT.	G.	CR.	CRT.	G.	CR.	CRT.	G.	CR.	CRT.	G.	CR.
SiO_2	73	73		52	52		144	144		78	78	
Al_2O_3	237	73	164	116	52	64	66		66	288	78	210
Cr_2O_3	240		240	257		257	276		276	250		250
Fe_2O_3	80		80	195		195	176		176	94		97
FeO	36	10	26	49	16	33	21		21	17	10	7
MgO	472	136	336	271	88	183	301	144	157	245	99	106

CRT.: Chromitite. G.: Gangue minerals. CR.: Chromite.

The following formulae are therefore constructed according to the method proposed by Thayer.

A: $Al_{35}Cr_{49}Fe_{16}(Mg_{93}Fe_7)$
A′. $Al_{12}Cr_{50}Fe_{38}(Mg_{85}Fe_{15})$
B. $Al_{13}Cr_{53}Fe_{34}(Mg_{88}Fe_{12})$
C. $Al_{37}Cr_{46}Fe_{17}(Mg_{93}Fe_7)$

An inspection of these formulae indicates that there are two types of chromites; one forming the center of the lenses contained in serpentine, such as A and C, and the other forming the margin of the large lens contained in serpentine, such as A′, or forming the lenses contained in talc carbonate, such as B. As described later, the second type of chromite is formed by alteration of the first. Nevertheless, the chemical composition of the different chromites in general and their formulae shows the following characters:

1. High percentage of MgO ranging from 85% to 93% of RO molecules. This percentage is even higher than the high magnesia-bearing chromites of

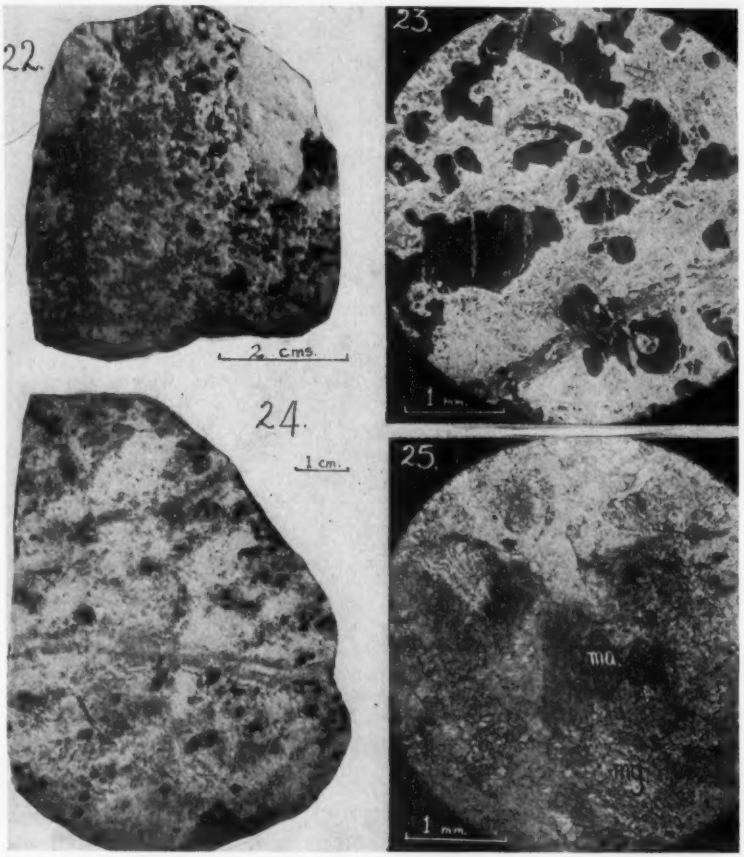

FIG. 22. Specimen of diffused ore formed of chromite grains in serpentine matrix.

FIG. 23. Thin section of the diffused ore of Fig. 22 showing rounded fine grains of chromite embedded in serpentine matrix. The chlorite crystals contain rounded relics of serpentine meshes.

FIG. 24. Specimen of diffused ore formed of chromite grains in talc carbonate matrix.

FIG. 25. Thin section of the diffused ore of Fig. 24. It shows a decomposed chromite grain in a matrix of talc and carbonate (cb). The decomposed chromite is replaced by magnesite (mg) and magnetite dust (ma).

the Caribbean Province or of the Pacific Coast which were described by Thayer (5, p. 213). Their magnesia does not exceed 75% of RO molecules. This high content indicates that chromites were formed in forsteritic rocks poor in ferrous oxide.

2. High content of Fe_2O_3. The least altered chromites have Fe_{16}. This value is even higher than the highest ferriferous chromites described by Thayer, which does not exceed Fe_{10}. The high percentage of ferric oxide is accompanied by a low percentage of ferrous, which is about (Fe_7). Consequently, the ratio of the Fe_2O_3 : FeO is high. This ratio as determined by Thayer indicates the high oxidizing condition, under which the chromites were formed.

3. High percentage of Cr_2O_3.

4. Low content of Al_2O_3.

5. R_2O_3 significantly exceeds RO.

These characters indicate that the chromite ores are generally rich in chromite and magnetite and poor in spinel molecules, and that they possess a high ratio of MgO : FeO. According to the investigations made by Thayer on the

TABLE III.

	FeO (mol)	MgO (mol)	Total	mg value	
A	26	336	362	92.8	Chromites
A′	33	183	216	84.7	
B	21	157	178	88.2	
C	7	106	113	93.8	
a	30	1012	1042	97.1	Silicate rocks
b	21	1003	1024	97.8	
c	35	888	923	95.5	

correlation of chromites with their containing rocks, it is assumed that the composition of the least altered chromites indicates that they were formed in association with feldspar-free peridotite, low in alumina and in iron oxide (olivine-enstatite rock).

The sequence of the crystallization of the chromites and the associated silicates (olivine and enstatite) could not be determined under the microscope due to the alteration of these minerals but it is roughly determined by comparing their chemical analyses. This comparison is based on the principle that the FeO in the magma tends to combine with Cr_2O_3 or TiO_2 if present, in preference to MgO. This goes on until the Cr_2O_3 and TiO_2 is consumed; then FeO combines with MgO to form silicates, *i.e.*, the presence of Cr_2O_3 deprives the magma of FeO so that the silicates formed after that will be poor in FeO. The same principle is used by Van der Walt in determining the sequence in the chromites of the Bushveld Complex (7). This was determined by comparing the relative amount of the FeO and MgO in the chromites and associated silicate minerals. Van der Walt used the ratio of MgO molecules to the sum of FeO and MgO molecules which he called the "mg value." The mg values of the chromites and the silicates examined in this area are given in Table III.

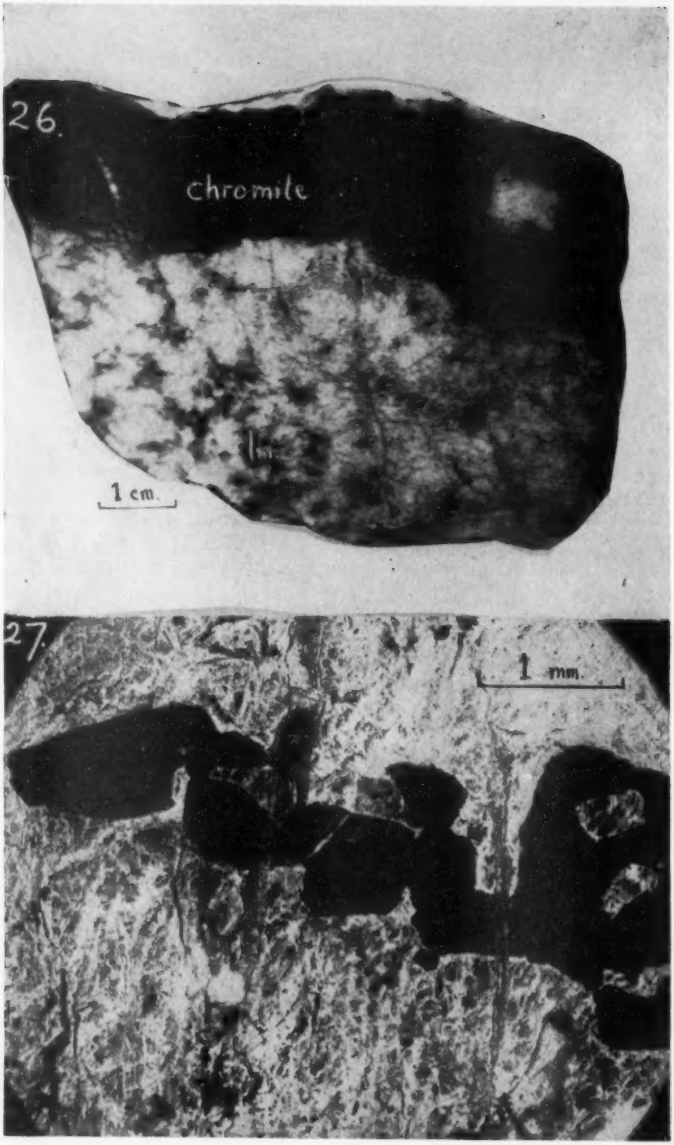

Fig. 26. Specimen of yellow serpentine cut by chromite veinlet. The serpentine rock contains dark patches of limonite (lm).

Fig. 27. Thin section of a small chromite apophysis traversing serpentine.

The mg values of the examined chromites and their associated silicates are very high indicating, as stated before, that the magma was rich in MgO. A comparison of these values with those of the Bushveld chromites gives the following results:

	mg value of chromites	mg value of silicate rocks
Bushveld	30–40	70–80
Area examined	84–92	95–97

The mg values of the chromites of the Bushveld complex are relatively lower than those of their associated silicates, while in the area examined the chromites and the silicates have equivalent values. This indicates that the chromites in Barramia and Umm Salatit crystallized independently of the silicate minerals; otherwise their magnesia values would have been complementary, as in the case of the Bushveld complex in which chromite crystallized during the crystallization of silicates.

Alteration of Chromites.—The chemical composition of the different chromites and their calculated formulae indicate that there are two types of chromite. One forming the center of lenses contained in serpentine, such as A and C, and the other forming the margin of the large lens contained in serpentine, such as A′, or forming the chromite lenses contained in talc carbonate, such as B. Thus, in the large lens of Deposit No. 1, type A forms the center of the body and A′ forms the margin. A comparison of the composition of the two types gives the following variations from the center to the border of the lens:

(a) Great decrease of alumina.
(b) Great increase of ferric oxide and small increase of ferrous iron.
(c) Great decrease of magnesia.

These variations may be regarded as either primary or secondary, but the consideration of the field relation of the two types and their mineralogical composition indicate that it is secondary. The chromite A′ is formed from A by action of magmatic and hydrothermal fluids. The following evidence supports this view:

1. Chromite A consists of subhedral angular crystals without fractures, while chromite A′ consists of rounded, fractured and embayed crystals.

2. The corroded chromite of type A′ is not only found on the margins of the lens but also within the body along the joints traversing it.

3. Other chromites which have the same chemical composition of A′ are found in talc carbonate, such as chromite B, while those with the composition of A are found in serpentine, such as C.

4. The chromites A and especially A′ have a high content of ferric oxide and a high ratio of ferric to ferrous. Their values are too high to be formed under normal magmatic conditions. Thus, a calculation of the norm of the chromite ores shows that the ferrous and magnesia molecules are insufficient to combine with the chromium oxide or alumina to form chromite or spinel molecules. Consequently, the ferric oxide will not find any ferrous to combine with to form magnetite molecules. This indicates the abnormal high content of ferric oxide which is even higher than that in the chromites of

Manitoba, which are regarded by Bateman to be ferriferous (8). The chromites of Barramia do not contain exsolved hematite such as that described from Manitoba. The only ferriferous mineral present is the black opaque chromite replacing the cherry red chromite.

This evidence indicates that the variation in the composition of chromites is due to alteration either by magmatic or by hydrothermal fluids later than the segregation and crystallization of the ore.

The chemical variations described above are explained mineralogically as follows:

1. The removed alumina from the altered chromite is assumed to be fixed in the chlorite instead of serpentine in the interspaces of the chromite crystals.

2. The removal of alumina leads to the concentration of iron oxide, which is explained by the formation of black opaque ferriferous chromite on the margins of the lenses contained in serpentine or throughout the lenses contained in talc carbonate. The concentration of iron oxide was produced under strong oxidizing conditions, so the increase of ferric oxide exceeds that of ferrous oxide.

3. The removal of magnesia is explained by the formation of magnesite in grains or veinlets. These are relatively insufficient to account for the removed magnesia, but perhaps the solubility of magnesite explains its deficiency.

These alterations are seen in the lenticular bodies as well as in the disseminated ore. The mineralogical study of the disseminated chromites in the talc carbonate offers a good example of alteration. The chromite crystals are replaced by magnesite and plenty of magnetite dust, indicating the liberation of magnesia and iron oxide. The alumina is collected in the chlorite lamellae which are found in the groundmass of talc.

ORIGIN OF THE CHROMITE DEPOSITS.

The chromite deposits and the associated silicate rocks were crystallized from an olivine-enstatite magma. The lenticular chromite bodies were not formed in situ, they were crystallized at a very early stage, then the solid ore bodies were carried by the silicate fluid, which was intruded and crystallized at a later stage. The intrusion of the silicate rocks was accompanied by a stress that controlled the localization of the solid lenticular ore bodies. The disseminated chromite deposits were formed during the crystallization of the silicate rocks. The chromite veinlets found in the serpentines and the chromite nodules found in the metamorphosed schistose rocks were formed after the crystallization of the silicate rocks. Both the silicate rocks and chromite deposits were subjected to the late hydrothermal fluids that serpentinized and steatitized the silicate rocks and altered the chromite deposits. The effect of this alteration is seen in the chemical composition of the ore and in its physical properties.

These conclusions were drawn from the field relations of the deposits as well as from the chemical and mineral composition of the ore deposits and the associated silicate rocks. These conclusions are discussed as follows:

As regards the composition of the magma from which the chromites segregated it is assumed to be a peridotite (olivine-enstatite) poor in feldspar con-

stituents, low in iron and in magnesium. This assumption is based on the investigations made by Thayer on the correlation of chromites with associated silicate rocks. The serpentine and the talc carbonate surrounding these deposits were proved by the same writer to derive from peridotites of nearly the same composition.

As regards the mode of formation of the chromite deposits and their sequence of crystallization in comparison with the associated silicate rocks, it is shown that the different deposits differ in this respect.

The Lenticular Ore Bodies.—These have segregated from the magma at great depth under conditions more favorable for crystal growth, as indicated by the texture of the chromite crystals and by their form. The comparison of the mg value of these chromites with those of the associated silicate rocks indicated that the chromite did not crystallize in situ but independently of the neighboring serpentine or talc carbonate. In addition, the high content of MgO and low content of FeO in the chromites indicates that they were formed at a very early magmatic stage. This led the writer to believe that the lenticular chromite bodies crystallized at a very early stage, at great depths, before the crystallization of the associated silicate rocks. This is confirmed by the scarcity of silicates in the center of the chromite bodies. The writer believes that the segregated chromite bodies were carried up to their present position as solid inclusions during the emplacement of the ultramafic bodies. Thayer (6) believed that the chromites of Cuba were formed in the same way.

The alignment of the chromite bodies in a northeast-southwest trend indicates the mobility of the ultramafic fluid which allowed the lenticular chromite bodies to be aligned parallel to the elongation of the intrusion and to the schistosity of the metamorphosed schistose rocks. These must have been controlled by regional stress affecting the whole area at the period of ultramafic emplacement.

The disruption of the chromite crystals at the borders of the bodies or along the joints indicates the solidity of the chromite bodies. The rounding and the embayment of the chromite fragments by chlorite indicates the mobility and the activity of the ultramafic magma which resorbed the chromite crystals after solidification.

The chromite bodies contained in the talc carbonate were fractured to tiny angular pieces and altered to an opaque black mineral. Also the margins of the chromite bodies contained in serpentine were altered in the same way. This change records the action of the hydrothermal fluids on the chromite deposits. This change also led to the concentration of iron oxide which gave the chromite the black color and led to the release of alumina, which formed the chlorite in the interspaces. These reactions either of magmatic silicate fluids or of hydrothermal fluids on the chromite have resulted in a change in the chemical composition of chromite. The least altered chromite is found in the center of the lenses contained in serpentine. The altered chromite is found on the margin of these bodies or in bodies contained in talc carbonate.

The Disseminated Ore.—The presence of subangular or rounded chromite crystals of medium texture in a mass of serpentine, plus the presence of relics

of mesh serpentine within these crystals, indicates that the chromite crystallized during the crystallization of the silicate minerals.

The disseminated ore was altered by the hydrothermal fluids in the same way as the lenticular ore bodies. The serpentine matrix changes to talc carbonate but the chromite alters to magnetite and magnesite. Some chlorite wisps were formed in the talc carbonate matrix.

The Chromite Veinlets.—The thin chromite veinlets indicate that the ore-forming fluid was sufficiently mobile to fill the thin fractures in the serpentine rock. The strong alteration of the serpentine containing the veinlets to a yellowish green rock indicates the strong action of hydrothermal fluids that deposited limonite. These led the writer to regard it as a late magmatic deposit formed by the hydrothermal fluids after the crystallization of the ultramafic magma. The mobility of the chromite fluid is preserved and increased by the presence of mineralizers whose presence retarded the crystallization of chromite as assumed by Singewald (9). The formation of late magmatic chromite has been previously described by Ross (10), Fisher (11) and Sampson (2).

The chromite crystals of the veinlets enclose angular interspaces filled with serpentine instead of chlorite. These indicate that the chromite veinlets were not altered by the hydrothermal fluids as were the other deposits but they were deposited by these fluids. The transportation and deposition of chromite by hydrothermal fluids is supported by the occurrence of small nodular pieces of chromite in the metasomatized schists occurring near the serpentine masses.

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FOUAD I UNIVERSITY,
CAIRO, EGYPT,
Jan. 9, 1947.

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DISCUSSION AND COMMUNICATIONS

THE MARLBORO CLAY.

Owing to the fact that most of the clay outcropping in the vicinity of Washington either has been removed or is in land that has become of prohibitive real-estate value, it is important now to call attention to the existence of a bed of excellent clay of Eocene age, but little utilized, underlying a wide area in the Coastal plain plateau east of Washington and extending south across Virginia.

It is 20 feet or more thick but for some miles just east of Washington its western edge is so buried under an overlap of Miocene sands onto sands of Cretaceous age that its presence to the east would not be suspected. It is the Marlboro clay constituting the lower member of the Nanjemoy formation, the uppermost formation of the Eocene succession, which I named Pamunkey formation in 1891. This succession was later classed as a group and subdivided by the Maryland Survey into Aquia and Nanjemoy formations.

In my later work for the U. S. Geological Survey and as an extension of that work under a grant from the Penrose fund of the Geological Society of America, I drilled nearly 200 holes with a 2-inch earth auger and ascertained the character and overlap relations of this Marlboro clay member. I found that its bevelled-off western edge lies not far east of Washington under later formations and that it is extensively exposed in valleys farther east and available in a wide area of the Coastal Plain in Maryland and Virginia east and southeast of Washington.

The description by the Maryland geologists unfortunately gives the impression that in places the member consists in part of "argillaceous sand," but I find that all of it is clay, mostly pink, consisting of aluminum silicate derived from the old crystalline rocks of the Piedmont region and quite suitable for terra cotta and brick manufacture as shown by tests in the Bureau of Standards.

The clay underlies the wide plateaus between Potomac and Patuxent rivers and Chesapeake Bay. It dips south under the Coastal Plain succession passing beneath tide water at Maryland Point on the Potomac, on the Patuxent about 5 miles south of Marlboro, and on Chesapeake Bay 8 miles south of Annapolis.

The Marlboro clay does not appear in the Good Hope Hill ridge east of Anacostia, owing to removal and truncation in Miocene time, so that from a point a mile east of Forestville to a point a mile north of Friendly, the Calvert formation extends across its western edge. It appears in full thickness on the ridge between Patuxent River and its two branches from the west in the Croom to Pindel region. It dips below sea level on Patuxent River a mile below Pindel postoffice. In the slopes about Marlboro it is especially con-

spicuous. It crops out along the west slope of the ridge to the northeast of Governors Bridge and along the north slope of this upland from a mile south of Rutland to sea level in South River at a point 2 miles east of South River postoffice. It appears again in the valley southeast of Birdsville and passes below sea level in the river 4 miles east of that postoffice.

It outcrops on both sides of the ridge on which Friendly is located, notably in slopes about Piscataway and to beyond Fort Washington. From the latter place the outcrop extends along the west slope of the high plateau to and beyond a point about one mile north of Accokeek. It crops on the north slope of the plateau at Marshall Hall, thence south past Fenwick and up the valley of Mattawoman Creek to a point northeast of Pomonkey. The outcrop extends past Marbury and past Rison beyond which it is covered by young deposits to a point just west of Maryland Point where it appears for a short distance before passing below sea level. It comes up in Virginia near Chatterton and crops out extensively in the north slope of the ridge west to beyond White Oak. Thence east it extends north of Rappahannock River to Hopyard, passing below sea level in the river at a point 3 miles north of Rappahannock Academy. It appears also in the ridges extending south from Stafford. It crops out on both sides of Accokeek Creek as far south as the latitude of a point 4 miles south of Rison.

All this will be shown in detail in the map, Plate 1 of a Bulletin of the Geological Society of America entitled "Structural Relations of Cretaceous and Tertiary Formations in Maryland and Virginia" soon to be issued.

Another clay 50 feet thick likely to be useful east and northeast of Washington is Raritan. It is separated by greensands of Upper Cretaceous and Eocene age.

N. H. DARTON.

WASHINGTON, D. C.,
Jan. 8, 1947.

REVIEWS

Précis de Géologie (Manual of Geology). By LÉON MORET. Pp. 637; figs. 313; map 1. Masson et Cie., Paris, 1947. Price, 900 frcs.

The author of this book admits that it might seem like an ambitious enterprise to try to summarize in a compendium most of the modern knowledge on all of the different aspects of geology, which has developed so greatly during the last hundred years.

The author treats first the constituent materials of the earth's crust, starting with the elements and minerals, under the heading of Notions of Mineralogy; then, under Petrography, the various rocks with their more or less complex associations of minerals.

The study of the chronological and geographical distribution of the rocks gives an opportunity to review the three most important branches of geology, i.e. Stratigraphy—relative relations of the strata; Paleontology—which describes and utilizes the fossils found in the sediments; and finally Tectonics—the science of the ulterior deformations of the lithosphere. All this leads to the account of the history of the earth—Historical Geology—which, in the opinion of the author, constitutes the ultimate purpose of geology.

Although this book is meant more particularly for graduate students who make geology an important part of their curriculum, it is nevertheless useful to geographers and engineers who have to become familiar with this science, so important to their work. Its concise and clear descriptions will appeal also to the ever increasing number of laymen who have become interested in geology, and if they wish to broaden their knowledge they can choose among the books listed in the excellent bibliography at the end of the book. If perchance this book led some to elect geology as a career, its purpose would be more completely fulfilled.

M. L. MIGNONE.

Benjamin Silliman, Pathfinder in American Science. By JOHN F. FULTON AND ELIZABETH H. THOMSON. Pp. 294; illustrations and photographs. Henry Schuman, New York, 1947. Price, $4.00.

This biography holds deep interest for all geologists and American scientists. Benjamin Silliman has been called "the father of American scientific education." He did lay the foundation of science education in the United States when he became a tutor at Yale in 1799. He was Yale's first professor of chemistry. He was sent to England with $9,000.00 in 1805 to purchase books and scientific equipment and there enlarged his knowledge of chemistry and medicine and developed a life-time love for mineralogy, geology and mining. Upon his return to Yale he arranged the purchase of the famed Gibbs collection of minerals and utilizing it introduced the first course in mineralogy in 1807, and incidentally the elective system at Yale. A course in geology was added and Silliman became well launched upon his career as a geologist.

In 1813 Silliman was primarily responsible for organizing the Yale Medical

School. In 1818 he founded the American Journal of Science, long known as "Silliman's Journal" and still being edited from Yale after 130 years of service. He established a great natural history museum (Peabody Museum) and founded the first galley of fine arts in an American college. In 1847 he played the leading part in the founding of the Sheffield Scientific School at Yale, for whose centenary this volume was written. Thus Silliman helped make Yale College into Yale University. One of the first Ph.D.'s from the Scientific School was awarded to his student, the genius, J. Willard Gibbs.

Silliman's writings on mineralogy, geology and mining geology attracted world wide attention and he became famed as a lecturer utilizing intriguing charts and exhibits. He journeyed in mining areas and several of his students founded State Geological Surveys, chiefly to aid in the development of mineral resources.

This volume holds further interest to the reader because the authors portray not only the life of a great scientific educator, but the development of Yale University and the life and customs of contemporary New England, for Silliman and his family are admirably presented in their Connecticut setting. The authors make it clear that Benjamin Silliman was a great pioneer in educational revolution and in making the world interested in Science. This book should belong in the library of every geologist and every scientist.

A. M. B.

The U. S. S. R.—A Geographical Survey. By JAMES S. GREGORY AND D. W. SHAVE. Pp. 636; figs. 71; tables. John Wiley and Sons. New York, 1947. Price, $4.25.

This volume was first published in London in 1944 and reprinted in the United States. It is a geographical survey of the Soviet Union in relation to its background. It shows how the Russia of today has evolved from pre-Revolutionary Russia by presenting material gathered mostly at first hand from works published in Russia, which, the author states, were previously difficult to obtain, but were made available in London for a serious geographical study.

Part I, General Survey, includes chapters on Structure and Relief, Climate, Soil Zones, Vegetation, Geographical Background of Russian Historical Development, Nationalities and Political Divisions, Agricultural and Industrial Development.

Part II, Regional Geography, contains chapters on the Lands of the North, Far East, Northern Sea Route, Southern Siberia, Soviet Asia, Urals, Povolzhye (lands along Volga), Caucasus and Crimea, Ukraine, Western and Central Regions, and the Baltic Countries. One chapter deals with transport, communications, foreign trade, and distribution of population in Russia. A final chapter deals with "Russia as a World Power." Maps and diagrams illustrate the text.

Of particular interest are the parts dealing with Russian Historical Development and Agricultural Development. The part dealing with the Industrial Development is rather scanty. It goes into coal and power development with little data since 1940. It refers in general terms to the older and newer Baku oil fields, and to the development of iron ores. The part on non-ferrous metals and minerals contains little of value. Part II on regional geology covers adequately the geographic features of the various regions.

The book brings together in one volume a great deal of information about Russia that ordinarily would not be available to students of geography and geology and should serve as a standard reference or text on Russian geography.

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BOOKS RECEIVED.

ALAN T. BRODERICK.

U. S. Department of the Interior—Geological Survey.

Bull. 954–A. Tungsten Investigations in the Republic of Argentina, 1942–43. W. C. SMITH and E. M. GONZÁLEZ. Pp. 36; pls. 17. Washington, 1947. *Progress report describing 4 mines which together produced 125 tons of concentrates in 1942. Replacements of metamorphosed limestone and vein fillings in schists, granite and aplite.*

Bull 957–C. Geophysical Abstracts 130, July–September, 1947. V. L. SKITSKY. Pp. 60. Washington, 1947. *Annotated.*

Geological Survey Water-Supply.

Paper 968–C. Topographic Characteristics of Drainage Basins. W. B. LANGBEIN and OTHERS. Pp. 31; figs. 4; tbls. 1; map 1. Washington, 1947. *Results of compilation of following features from topographic maps of 340 drainage basins; area, stream length, density and slope, channel slope, area-altitude distribution, water body area. Results show all are interrelated, especially slope-altitude-basin area and stream density-land slope.*

Paper 997. Floods in Colorado. ROBERT FOLLANSBEE and L. R. SAWYER. Pp. 151; pls. 3; figs. 3. Washington, 1948. *Compilation of data on Colorado floods since 1826. Correlation between intensive grazing and increased runoff traced. Progress in flood protection described.*

Field Tests for the Common Metals (Ninth Edition). G. R. FANSETT. Pp. 55. Arizona Bur. Mines, Tech. Series No. 42, Bull. 154. Tucson, 1948. *Useful handbook of blowpipe and other tests. Arranged alphabetically by minerals and elements. U. S. and Arizona Mining statutes.*

Vanadium Deposits Near Placerville, San Miguel County, Colorado. R. P. FISCHER, J. C. HAFF and J. F. ROMINGER. Pp. 17; maps 2; fig. 1. Colorado Scientific Society Proc. Vol. 15, No. 3. Denver, 1947. *Extensive roscoelite-bearing sheets near top of Upper Jurassic Entrada sandstone. Workable deposits found where sheets cross bedding at sharp angle. Origin unknown. Writers suggest control by former water table or groundwater change interface. Large areas of potentially ore bearing ground as yet unexplored.*

Reservoir Sedimentation in the Sacramento-San Joaquin Drainage Basins, California. C. B. BROWN and E. M. THORP. Pp. 69; tbls. 7; map 1. U. S. Dept. of Agriculture, Soil Conservation Service, Sedimentation Section, Special Report No. 10. Washington, 1947. *Effects of sedimentation on life and operation of flood-control and multiple-purpose reservoirs proposed for this area.*

Illinois Geological Survey.

Circ. 131. Plant Microfossils in Correlation of Coal Beds. R. M. KOSANKE. Pp. 5; fig. 1. Urbana, 1947. *Results of intensive study of fossil microspores, isospores, prepollens from Pennsylvanian coals in Illinois show them to be valuable in correlation.*

Circ. 132. Agstone used in Illinois in 1946. W. H. VOSKUIL, D. F. STEVENS and E. M. KING. Pp. 9; tbls. 5; map 1. Urbana, 1947. *Statistics on production of ground limestone, dolomite and marl used in soil treatment.*

Circ. 133. A Comparative Study of Stigmarian Appendages and Isoetes Roots. W. N. STEWART. Pp. 9; figs. 3. Urbana, 1947. *Two structures are homologous, size being the greatest difference.*

Circ. 135. Reflections on Recent Diamond-Drill Exploration in the Illinois Coal Field. G. H. CADY. **Use of International Business Machine Technique in Tabulating Drilling Data.** M. A. PARKER. Pp. 9; figs. 3. Urbana, 1947.

Circ. 137. Transparent Model of Reservoir Showing Displacement of Oil by Conjoint Use of Gas and Water. FREDERICK SQUIRES. Pp. 4; figs. 8. Urbana, 1947. *Gas injected above oil while water is injected below should maintain initial pressure and production rate throughout pool's life.*

Circ. 138. Certain Geological Conditions that Cause Coal Mining Fatalities. R. W. ROLEY. Pp. 3; figs. 3. *Roof-falls usually due to unnoticed roof rock changes, gas pressure or chemical changes, old fractures. Importance of geologic study in safety program emphasized.*

Rep. of Inv. 123. I. Reaction of Different Clay Minerals with some Organic Cations. II. Reaction of Clays with Organic Cations in Producing Refractory Insulation. R. E. GRIM, W. H. ALLAWAY and F. L. CUTHBERT. Pp. 17; figs. 2; tbls. 4. Urbana, 1947. *Part I shows clay's water absorption capacity is much reduced by treatment with solution containing large organic cations. Part II suggests practical applications of this fact in manufacture of insulating refractories.*

Rep. of Inv. 124. Geological Structure of the Zinc-Lead District of Northwestern Illinois. H. B. WILLMAN and R. R. REYNOLDS. Pp. 15; pls. (maps) 7. Urbana, 1947. *Most deposits near synclines. Considerable likely ground as yet unexplored. Detailed descriptions of key beds given. Structures contoured on maps at 10-foot interval, scales 2", 5", 6" to mile.*

Rep. of Inv. 125. Relation of Clay Mineralogy to Origin and Recovery of Petroleum. R. E. GRIM. Pp. 8; fig. 1. Urbana, 1947.

Rep. of Inv. 126. Role of Microfossils in Interregional Pennsylvanian Correlations. C. L. COOPER. Pp. 9; tbls. 2. Urbana, 1947.

Press Bull. Series No. 56. Oil and Gas Development in Illinois in 1946. A. H. BELL and VIRGINIA KLINE. Pp. 49; figs. 2; tbls. 8. Urbana, 1947.

Subsurface Geologic Cross Section from Trego County, Kansas, to Cheyenne County, Colorado. J. B. COLLINS. Pp. 8; section, vert. scale 1" = 200', hor. scale 1" = 6 miles. Kansas Geol. Survey, Oil and Gas Investigations, Preliminary Cross Section No. 5. University of Kansas. Lawrence, 1947. *Based on cuttings from 9 rotary wells, electric logs from 3. Paleozoic rocks.*

New Mexico Bureau of Mines and Mineral Resources—Annual Report—2, for the Fiscal Year July 1, 1946–June 30, 1947 (Includes Annual Report of State Inspector of Mines). E. C. ANDERSON. Pp. 49. Socorro, 1947. *Usual departmental report.*

The American Association of Petroleum Geologists Index. D. W. HEATH. Pp. 603. Tulsa, Oklahoma, 1947. *Bibliography of all A.A.P.G.'s publications from 1917 to 1945. Not annotated.*

Brazil—Ministério da Agricultura, Departamento Nacional da Produção Mineral, Divisão de Geologia e Mineralogia.

Relatório Anual do Diretor, 1944. M. G. DE OLIVEIRA ROXO. Pp. 120. Rio de Janeiro, 1947. *Director's Annual Report for 1944.*

Bol. 100. Histórico do Serviço Geológico e Mineralógico e Considerações sobre suas Atividades. Índice dos Boletins 1–99. Pp. 223. Rio de Janeiro, 1946. *History of Brazilian geology and mineralogy. Abstracts of first 99 bulletins.*

Bol. 121. A Província Magmática de Roroimã. DJALMA GUIMARÃES. Pp. 107; pls. 11; figs. 12. Rio de Janeiro, 1947. *Petrography and petrology of a group of basic rocks—norites, dolerites, gabbros, basalts. Enstenitization of pyroxenes and zoning of plagioclase believed related.*

A Century in the History of the Geological Survey of Canada. F. J. ALCOCK. Pp. 94; pls. 62. National Museum of Canada Special Contribution No. 47–1. Ottawa, 1947. *Engrossing story of the growth of the Canadian Geological Survey.*

Geology of Highwood-Elbow Area, Alberta. J. A. ALLAN, J. L. CARR and P. S. WARREN. Pp. 75; figs. 20; pls. 7; tbls. 2; map, colored, 1″ = 1 mile. Alberta Research Council, Report No. 49. Edmonton, 1947. *Geomorphology, stratigraphy, structure, economic geology, paleontology of area of Mesozoic rocks. Faulting and folding has raised rank of most of the coal to low volatile bituminous, some to semianthracite. No production to date.*

Quebec Department of Mines.

The Mining Industry of the Province of Quebec in 1945. Pp. 177; figs. 2. Quebec, 1946.

Geol. Rep. 17. Siscoe Mine Map-Area, Dubuisson and Vassan Townships, Abitibi-East County. P. E. AUGER. Pp. 40; figs. 9; map, colored, 1″ = 1000′. Quebec, 1947. *Quartz-tourmaline-gold and quartz-pyrite-gold veins, quartz-gold lenses in shears in and near a granodiorite batholith and nearby stocks. Writer suggests ore-intrusive relationship may be structural, not genetic.*

Geol. Rep. 27. Desvaux Lake Area, Dasserat Township, Rouyn-Noranda County. P. E. AUGER. Pp. 23; pls. 9; map, colored, 1″ = 800′. Quebec, 1947. *Areal geology, structure. No known economic deposits.*

Bibliography of Seismology, No. 1, Items 6357–6504, January to June 1947. W. G. MILNE. Pp. 19. Dept. of Mines and Resources, Canada, Publications of the Dominion Observatory. Ottawa, 1947. *Partly annotated.*

Carta Geológica de la Parte Septentrional de la República Mexicana. P. B. KING. Pp. 24; figs. 4; maps 2. Cartas Geol. y Min. de la Rep. Mex. No. 3. Universidad Nacional Autónoma de México, Instituto de Geología, Geofísica y Geodesia. Mexico, D. F., 1947. *Two uncolored geologic maps of Mexico, north of 20° latitude. One at 1″ = 40 miles shows areal geology. Other at 1″ = 70 miles shows tectonics. Contains bibliography of information sources.*

Turkey—Publications of the "Maden Tetkik ve Arama Enstitüsü Mecmuasi." (Texts in Turkish and French.)

No. 2/32. La Métallogénie de l'Ancien Gîte de Pyrite Cuivreuse de Küre, du Gîte Nouvellement Trouvé d'Asiköy et de la Zone Côtière (Centrale et Est) de la Mer Noire. V. KOVENKO. Pp. 32; tbls. 4; figs. 6; maps 2. Ankara, 1944. *Replacements of limestones. Paragenesis—magnetite, pyrite, chalcopyrite and quartz. Deposits related to regional tectonics.*

No. 2/34. Filons de Chromite du Type d'Injection de la Région de Bursa, Turquie. V. KOVENKO. Pp. 10; figs. 4. Ankara, 1945. *Differentiation order from cross-cutting relationships: harzburgite, dunite, chromite, dunite and gabbro. Main chromite masses believed formed by injection, minor seams by lateral secretion of residual fluids from walls.*

No. 1/35. Province Métallogénique de Plomb et de Fer des Taurides, Turquie. V. KOVENKO. Pp. 40; figs. 8; map 1. Ankara, 1946. *Author divides Turkey into 6 metallogenetic provinces and describes the Pb-Fe province in detail. Deposits largely limestone replacements near fissures. Abundant solution cavities near Pb-Zn bodies believed to have been formed by same emanations as ore.*

No. 2/36. Mines de Plomb de Gümüşhaciköy et de Karasu, Province Nord de Plomb. V. KOVENKO. Pp. 15; maps 2; fig. 1. Ankara, 1946. *Limestone replacements.*

No. 1/37. Quelques Mines de Plomb, de Zinc et d'Antimoine de la Province Nord d'Anatolie (Denek, Akdag, Zara et Turhal). (Some Lead, Zinc and Antimony Mines of the North Anatolie Province.) V. KOVENKO. Pp. 35; figs. 4; maps 2; microphotos 2. Ankara, 1947.

L'esplorazione Mineraria della Libia (The Mineral Exploration of Lybia). ARDITO DESIO. Scientific Collection of the Ministry of Italian Africa, Vol. X. Pp. 333; figs. 39; photos 31; map 1. Milano, 1943. *Stratigraphy, geochemistry and chemical analysis of phosphate deposits; results of prior investigations; up to 1942 no deposits of industrial interest found. Geological and chemical investigations on the salt of the Lybian sebkas. Chemical research on the limestone, marl and clay of Tripolitania.*

Twelfth Annual Petroleum Number of the Mines Magazine. Pp. 96. Denver, November, 1947. *Well-known annual review of the petroleum industry, covering exploration, geophysics, drilling, transport, storage and research.*

SCIENTIFIC NOTES AND NEWS

The Industrial Diamond Review of London announces that it has a list of 120 different reprints of its articles, available free to readers of this journal.

The Division of the Geological Sciences, California Institute of Technology, announces the appointment of Dr. R. Dana Russell as Visiting Professor, and of Dr. C. Hewitt Dix as Associate Professor, effective January 1, 1948. Dr. Russell, Consulting Geophysicist for the U. S. Navy Electronics Laboratory, will work in sedimentary petrology, a field to which, while he was on the staff of the Louisiana State University, and as a member of the Sub-Committee on Sedimentation of the National Research Council, he has made many contributions. Dr. Dix, who has been a geophysicist with the United Geophysical Company for the past six years, will specialize in the seismic and gravitational phases of applied geophysics. It was announced earlier that Dr. Hampton Smith, formerly Chief Geologist of the Texas Company, has been appointed Lecturer in Petroleum Geology.

Since his connection for somewhat over forty years with mining in the Belgian Congo, SYDNEY H. BALL, of the firm of Rogers, Mayer and Ball of New York, has been decorated three times by the Colonial Government for furthering the development of mining in that colony. First as Chevalier de l'Ordre Royal du Lion, later as Officier de l'Ordre Royal du Lion, and in January, 1948, as Commandeur de l'Ordre de Léopold II.

JOSEPH J. BEESON, mining geologist and engineer, formerly chief of Exploration Section, Office of Premium Price Plan, Washington, D. C., announces the reopening of his consulting office in the Dooly Building, Salt Lake City, Utah.

After four years as consulting mining engineer to the Government of Venezuela, JOHN C. DAVEY returned to England and accepted to be general manager of The Egyptian Phosphate Co., which is interested in the African phosphate industry and operates a group of mines in Egypt.

After completing some examination work in northern, western and central British Columbia, JOSEPH T. MANDY has returned to Vancouver, B. C.

The mining division, Arizona section of the American Institute of Mining and Metallurgical Engineers, has elected as chairman CARROL WEED, general superintendent of Inspiration Consolidated Copper Co., to succeed WESLEY P. GOSS.

The American Institute of Mining and Metallurgical Engineers has elected president WILLIAM E. WRATHER, director of the U. S. Geological Survey, Washington, D. C.

HUGH H. BEIN has left for the Philippine Islands after resigning from Best Mines Co., Downieville, Calif.

WILLIAM JAMES BICHAN, assistant professor of geology at the University of New Brunswick, Canada, and recently in charge of mineral exploration in the pre-Cambrian formations of that province, has been appointed director of mineral resources in the provincial department of natural resources.

S. S. GOLDICH of the Texas Bureau of Economic Geology has been on leave of absence since April 1947 investigating bauxite deposits for the Federal Government. He was in the South Pacific for several months conducting field work but

now is in Washington, D. C., completing reports and will return to Austin about April 1, 1948.

The Bureau of Economic Geology, at the University of Texas, Austin, Texas, announces staff changes as follows. BERNHARD KUMMEL joined the staff July 15, 1947, and is engaged in Mesozoic stratigraphy and paleontology. HELEN JEANNE PLUMMER joined the staff February 1, 1948, for research in micropaleontology and stratigraphy. HENRY F. NELSON will join the staff February 15, 1948, to be engaged in general and economic geology. H. B. STENZEL, in addition to his duties in the Bureau, has been appointed graduate professor of geology in the Department of Geology. He will offer an advanced course in Tertiary paleontology and stratigraphy during the second semester of the present school year.

The Bureau has decided to start a comprehensive summary of the oil fields of Texas under the direction of FRANK A. HERALD who joined the staff January 1, 1948. Successful completion of this project will require the cooperation of the geologists of Texas. It is hoped that a plan can be made to work with the local geological societies in the project and that members of the societies will be willing to share in authorship of the publication. Within the next few weeks Mr. Herald and the Director will visit the geological societies to discuss plans for the project.

The American Institute of Mining and Metallurgical Engineers held a very successful meeting in New York, February 15th to February 19th. The Mining Geology Committee, under the able Chairmanship of Carlton D. Hulin, had an unusually good program with well attended technical sessions. Some of the papers presented under the Mining Geology Committee were: *Occurrence and Mining of Solid Bitumens in Argentina,* by H. A. Meyerhoff; *Occurrence of Pyrophyllite in Pennsylvania,* by R. C. Stephenson; *Bedding Replacement Fluorspar Deposits in Illinois,* by R. M. Grogan; *Chert in the Kingsport Formation at Mascot, Tennessee,* by A. T. Allen, Jr.; *Iron Ore Deposits of the Western Province, Liberia,* by T. P. Thayer, A. P. Butler, Jr., and W. H. Newhouse; *Iron Ore Reserves of Michigan,* by F. G. Pardee; *Some Observations Regarding the Ore Deposits of the Tri-State District,* by G. M. Fowler; *Some New Concepts Regarding the Age, Areal Distribution, and Mineral Assemblages of the Ore Producing Districts in the Central States Region,* by D. R. Stewart; *Gold Deposits Renabie Mine Area, Ontario,* by M. H. Brohberg; *The Mercury Industry of Italy,* by E. B. Eckel. The paper by R. H. Sales and Charles Meyer on *Wall Rock Alteration at Butte, Montana,* was the outstanding paper of the last decade.

The Petroleum Division also had its customary supply of foreign and domestic production review and a number of excellent papers by prominent authors.

The Mineral Economics Division presented two technical sessions with a group of outstanding papers such as: *Mineral Policy Developments in Washington,* by James Boyd; *The National Security Resources Board,* by A. M. Hill; *Military and Mineral Strategy of the Great Powers,* by Col. G. A. Lincoln; *Mineral Problems of the European Recovery Program,* by R. P. Koenig; *Tariff Cuts on Mineral Raw Materials under the Reciprocal Trade Agreements Program—A Consumer Viewpoint,* by A. H. Phelps; *What Price Gold?,* by A. Notman and R. H. Bedford; *Gold vs. Inflation,* by D. H. McLaughlin; and *Subsidies for Domestic Mineral Producers,* by Evan Just.

In addition, the Pan-American Institute of Mining Engineering and Geology, United States Section, presented two technical sessions with ten papers generally relating to Mineral Deposits and Geology of Latin American areas.

William E. Wrather was installed as the incoming President of the American Institute of Mining and Metallurgical Engineers.

The annual meeting of the Institute in 1949 is to be held in San Francisco instead of New York.

The National Research Council, at the request of Admiral Paul F. Lee, Chief of Naval Research, has appointed the following committee of scientific investigators to advise the Geophysics Branch of the Office of Naval Research regarding scientific and related aspects of their research programs: W. H. Newhouse (Chairman), H. H. Hess (Vice-Chairman), Roland F. Beers, Maurice Ewing, Ellis A. Johnson, Lester E. Klimm, William C. Krumbein, William W. Rubey and J. Frank Schairer.

Dr. R. C. Gibbs, Chairman of the Division of Mathematical and Physical Sciences of the NRC, acts as Administrative Adviser to the Committee, in collaboration with Dr. Arthur Bevan, Chairman of the Division of Geology and Geography.

As stated at the first meeting on January 7 and 8, 1948, in Washington, the Geophysics Branch of the Office of Naval Research is charged with sponsoring basic research in appropriate fields of earth sciences through financial and other support of worthy projects and the Committee will, for the present, restrict its consideration to research problems dealing with the crust of the earth and the properties of the earth as a whole.

Since the ONR sponsors research in fields not adequately covered by other agencies, the Geophysics Branch and the Committee have established the following objectives for Research:

1. To foster, in cooperation with other agencies, geological, geographical, and geophysical explorations of little known areas of the earth such as the islands of the Western Pacific and the Arctic and Antarctic. Such exploration may include all aspects of the natural environment and problems of human and economic geography and ethnography as well as the more limited objectives implied in the terms geology and geophysics.

2. To conduct laboratory and field studies leading to a greater understanding of the properties and processes existing in the outer hundred kilometers of the earth's crust.

3. To develop instruments and techniques for determination of the earth's properties; for example, universal airborne magnetometer equipment.

The Office of Naval Research has adopted the policy of avoiding formulation, detailed direction, and "farming out" of projects for basic research in the belief that maximum progress and results will be realized if projects for investigation grow out of the ideas and interests of the investigators themselves. The Committee endorses this policy and will seek at all times, through advice and recommendations, to further its operation to the maximum degree possible. The submission of significant and well organized research proposals will be helpful in this connection.

For further details consult the Office of Naval Research, Navy Department, Washington 25, D. C., or the National Research Council, 2101 Constitution Avenue, Washington 25, D. C.

WALLACE E. PRATT received the Anthony F. Lucas Medal at the A.I.M.M.E. meeting in New York, February 18th.

A. J. BUTLER, General Secretary, 18th International Geological Congress, has heard that there are many Americans who are dubious about attending the Congress in England because of transportation problems and food in England. He states that Cooks and Cunard think that sailings can be arranged without difficulty and that the food situation probably appears worse in press reports than in actuality and that conditions will be found less rigorous than is generally thought. In response to the large number of Americans who registered provisionally, the excursions were extended. Mr. Butler states that the success of the Congress will largely depend on the presence of these Americans and hope is expressed that they will attend.

The American Association of Petroleum Geologists will hold its thirty-third annual meeting in Denver, Colorado, April 26 to 29, along with the Society of Economic Paleontologists and Mineralogists, and the Society of Exploration Geophysicists.

The Rocky Mountain Association of Geologists is the host organization; and Thomas S. Harrison is the general chairman of the committee on convention arrangements, with Arthur E. Brainerd acting as general vice-chairman.

The technical program is to include papers pertaining to the Rocky Mountain area except in a few cases of a special interest and it will begin on April 26 with a paper on the hydrogenation of coal by V. F. Parry of the U. S. Bureau of Mines coal research station. Tuesday morning will be devoted to the opening of the convention, the presidential addresses for the three societies and the presentation of awards. The afternoon session will include papers on the occurrence of oil in the Arbuckle and Ellenburger formations, on the "Golden Trend" of McLain and Garvin Counties, Oklahoma, and on the Leduc oil field of Alberta, Canada.

April 28 will be devoted to a symposium of the Rocky Mountain region, in which general papers will be given on the orogeny of the Front Range and on a résumé of oil-finding and on Western oil fields. April 29 will include papers on coral-reef production, the Permian Basin, and on gas resources.

GEORGE HEIKES has become associated with the Kennecott Copper Corporation, New York City, in charge of exploration.

MATT S. WALTON, JR., of the Department of Geology of Columbia University, has accepted the position of instructor in geology at Yale University, commencing next fall.

JOHN S. STEVENSON, of the British Columbia Department of Mines, Geology Section, was a recent visitor at several of the Eastern Universities.

The U. S. Geological Survey, Washington, D. C., announces that the demand for competent geologists far exceeds the supply.

MACK C. LAKE has made another trip to Venezuela in connection with the development of iron ore properties of which he has been in charge.

ANTON GRAY has gone to South Africa and will reside in Johannesburg for the next year or two to take charge of South African gold developments for the Kennecott Copper Corporation.

RALPH W. STONE, a charter member of the Society of Economic Geologists, who retired from the position of State Geologist of Pennsylvania, December 31, 1946, is giving a course in geology at Wilson College, Chambersburg, Penna., from February to May 1948.

J. A. RETTY, Chief Geologist of the Labrador Mining and Exploration Company, delivered a series of three lectures dealing with the geology and iron deposits of Labrador at Queen's University, Kingston, Ontario, during the second week of February.

FRED SEARLS, JR., president of the Newmont Mining Corporation in Nevada, expects to leave for Europe shortly, where he has been requested to make a survey of the coal production problems of the Ruhr Valley in Germany.

MURRAY F. CROSSETTE, former general manager, Santa Maria del Oro Mines Company, Magistral, Durango, is now operating the Mecatona mine, Roncesvalles district, Parral, Chihuahua.

H. J. FRASER has been appointed general manager and assistant to the president of Falconbridge Nickel Mines, Ltd.

M. D. GARRETTY, formerly consulting geologist to the North Broken Hill, has rejoined the firm as chief geologist and is directing an extensive exploration program in a search for new ore deposits.

RENO H. SALES has retired from active duty as chief geologist of Anaconda Copper Mining Co. He will be retained by the Company as consulting geologist, devoting his time to investigation and study of ore deposits. VINCENT D. PERRY, formerly assistant chief geologist in charge of outside exploration, succeeds Mr. Sales and will have headquarters in New York City. MURL H. GIDEL, now assistant chief geologist in charge of the geological department in Butte, will supervise geological work in all the Company's mines in North America. CHESTER H. STEELE, Mr. Gidel's assistant, will be in charge of the Butte geological department. ALEX MCDONALD, who was Mr. Perry's assistant, will have charge of outside exploration work in Western United States.

GUY RIDDELL is in Korea as mining advisor to the U. S. Military Government.

H. C. GUNNING, who resigned recently as professor of economic geology at the University of British Columbia, has opened offices as consulting geologist in the Yorkshire Bldg., Vancouver, B. C.

ROBERT A. DREYER, associate professor of geology, has been appointed as chairman of the department at the University of Kansas, to succeed PROF. L. R. LAUDON who has announced his resignation to go to the University of Wisconsin after the spring semester.

HUGH D. MISER, geologist, United States Geological Survey, Washington, D. C., has been elected to honorary membership in the American Association of Petroleum Geologists. This is the highest membership honor in the Association and only thirty geologists have been thus distinguished during the 30-year history of this society of explorers for petroleum. Dr. Miser will be presented with a certificate at the annual meeting in Denver, Colorado, April 27, in recognition of his "distinguished service to the cause of petroleum geology."

A. I. LEVORSEN, widely known petroleum geologist, and Dean of the School of Mineral Sciences at Stanford University, California, has been named recipient of the Sidney Powers Memorial Award of the American Association of Petroleum Geologists. The award was made "in recognition of distinguished and outstanding contribution to, and achievements in, petroleum geology," and this honor will be conferred at the annual meeting of the A.A.P.G. in Denver, April 27.

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